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Chapter 3

VENTILATION AND THERMAL STRESS ASHORE AND AFLOAT

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VENTILATION AND THERMAL STRESS ASHORE AND AFLOAT

Chapter 3

Section I. DEFINITIONS AND INSTRUMENTATION

Purpose 3-1
Definitions and Instrumentation 3-2

3-1. Purpose

(1) The purpose of this chapter is to provide information on the fundamentals of heating, ventilating and cooling, and to describe the physical and physiological measurements which must be made ashore and afloat in order to assess the effects of hot and cold atmospheric conditions on personnel.

(2) Engineering aspects which relate to heating, ventilation and cooling design in shipboard situations come under the cognizance of the Naval Sea Systems Command; those applying to shore establishments are handled by the Naval Facilities Engineering Command. Health standards governing these installations are promulgated by the Naval Medical Command. In order to protect the health and well-being of all personnel, it is important to be familiar with the fundamental principles involved in heating, ventilation and air-conditioning as they apply to the human.

3-2. Definitions and Instrumentation

(1) *Stress and Strain*

(a) The thermal (heat or cold) stress of any given working situation is the combination of all of those factors which result in heat gains or losses relative to the body or which prevent the body's regulatory mechanisms from working efficiently. Thus, it is necessary to consider the combined impact of climatic and non-climatic factors and to evaluate independent and integrated influences associated with the human.

(b) In accordance with engineering practices, environmental physiologists employ the term "stress" to designate the force or load acting upon the biological system and the term "strain" to designate the resulting distortion of the biological system. Thermal *stress* factors are conventionally given as heat, cold, humidity, radiation, air movement and surface temperatures; thermal *strain* manifests itself in specific cardiovascular, thermoregulatory, respiratory, renal, endocrine, etc., responses which differ from accepted human norms.

(c) It must be understood that not all thermal stress and strain are adverse to humans. Within the range of human adaptability, factors that do not impair performance or increase susceptibility to other risks may be considered "acceptable" until proven otherwise. Due to the fine line between acceptable and unacceptable levels of heat stress and strain, extreme caution must be exercised to avoid cumulative harm to individuals.

(d) Thermal stress has been categorized as:

(1) "Acceptable" when the human is *able to compensate without undue strain;* or,

(2) "Unacceptable" when the human is *able to compensate but incurs severe strain,* or is *unable to compensate and incurs excessive strain.*

(e) Thermal strains have been categorized as:

(1) Those interfering with work performance and safety; and,

(2) Those with more overt manifestations of physiologic decomposition such as heat rash, heat cramps, heat exhaustion, heat stroke, non-freezing or freezing injuries.

(2) *Climatic Measurements of Thermal Stress:*

(a) *Dry-Bulb Temperature* (DB) of air is that temperature measured with an ordinary alcohol-in-glass, or mercury-in-glass, thermometer whose bulb is kept dry and shielded from radiation. When laypersons speak of the prevailing air temperature, determined from a conventional thermometer, they are speaking of the dry-bulb temperature. A variety of electronic sensors can be used in place of conventional thermometers; if properly constructed some of these (e.g., thermocouples and thermistors) may require comparatively little shielding from radiant heat transfer. For routine monitoring of dry-bulb temperatures in shipboard spaces, the Naval Sea Systems Command approved alcohol-in-glass dry-bulb thermometer has the stock number 9G-6685-00-243-9964.

(b) *Wet-Bulb Temperature* (WB) is measured with a thermometer, similar to that used for dry-bulb temperature, except that a wet wick is fitted closely over the bulb (or sensor). A "natural" wet-bulb temperature is defined as that obtained with no additional movement of air over the wick than that which occurs naturally in the environment. An "aspirated" wet-bulb temperature is obtained by increasing air movement over the wick with a fan, motorized psychrometer, or sling psychrometer. The "true" wet-bulb environmental temperature is approximated with an air flow of at least 250 feet per minute (fpm) over the wick and the bulb is shielded from radiant heat. Excessive air velocity (e. g., greater than 1500 fpm) may result in a significant degree of kinetic heating. Although the natural wet-bulb temperature depends on the dry-bulb temperature and the moisture content of the air, it does not provide a direct indication of the amount of water vapor in the air. The *aspirated* wet-bulb temperature is therefore of greater value in planning corrective engineering actions than the "natural" wet-bulb temperature, and the term *wet-bulb* will hereafter refer to that which is *aspirated* unless otherwise specified.

When the wet- and dry-bulb temperatures are identical the air is said to be "saturated;" and the relative humidity may be considered to be 100 percent. Any decrease in the moisture content of the air will result in evaporation from the wetted wick of the wet-bulb thermometer, and in turn, the bulb of the thermometer will be cooled to a temperature which reflects the reduced moisture content of the air.

(c) *Measurements of Humidity.* Humidity is an expression of the quantity of water vapor mixed with the other atmospheric gases. The Absolute *Humidity* (AH) is the mass of water vapor present per unit volume of air (kg/m'); the gas pressure (Torr) exerted by this water vapor is referred to as the *Vapor Pressure (e* or VP). The ratio of the actual amount of water in the air (absolute humidity) to the maximum quantity of water that the air can hold at a given temperature is the *Relative Humidity* (RH). The temperature at which the absolute humidity reaches a maximum and the air become saturated with water vapor is called the *Dew Point* (Td).

Vapor pressure is a measure of water content in the atmosphere under given conditions. Relative humidity is primarily a ratio of partial and saturated vapor pressures, not a measure of water content. For example, one may find a 50 percent relative humidity at 50 F DB and 100 F DB, but the actual water content at 100 F DB will be nearly six-fold greater than that at 50 F DB (See Figure 3-1). Therefore, the proper evaluation of thermal conditions requires specifying both dry- and wet-bulb temperatures.

(d) *Psychrometer—an* instrument for measuring atmospheric humidity utilizing a dry- and wet-bulb thermometer and whirled manually or by motorized unit to provide the moderate air flow necessary to obtain an aspirated wet-bulb temperature reading. Psychometric charts (Figure 3-1) help translate this information into relative humidity and other thermodynamic characteristics of moist air. It is strongly recommended that *motorized psychrometer* be used for reproducibility of measurements; in turn, the stock number for the approved unit is 1H-6685-00-935-1389, calibration is not required. Electronic, motorized psychrometer are available to provide direct readout of DB, WB, RH and Td.

(e) *Air Movement or Velocity* (V) is usually expressed in feet per minute (fpm) or cubic feet per minute (cfm). It is measured by various instruments depending upon the velocities of air movement. Low velocities (down to 10 fpm) require a heated Kata thermometer or thermo-anemometer ("hot-wire" anemometer or equivalent); high unidirectional air velocities may be measured with a velometer or vane anemometer.

(f) *Radiant Heat is* the transfer of thermal energy by wave motion from one object to another without warming of the intervening space. The wave lengths involved range from the visible portion of the electromagnetic spectrum (0.3-0.7 microns) to the longer radio waves. In industrial situations any part of the heat radiation spectrum may be present. Natural environments, however, generally include two bands: solar radiation from ultra-violet to near infrared, and heat radiation in the far infrared portion of the spectrum. For recall it is easier to remember that solar radiation is a shorter wavelength and heat radiation (e.g., indoors) is a longer wavelength. Both forms of radiation liberate thermal energy when absorbed.

Not all of the radiant heat that strikes a surface is absorbed. Any surface which has a high reflectance will minimize absorption of radiant heat; conversely, a surface with low reflectance will increase absorption of radiant heat. The portion that is absorbed is termed "absorptance of the surface" while that which is not absorbed is reflected by the "reflectance of a surface". An exception exists for humans in that dark-pigmented skin and light-colored skin are essentially alike in absorbing the longer wavelength radiant heat (e. g., indoors); however, in the sunlight darker skin has a higher absorptance than lighter skin. The intensity of radiant heat can be measured by use of a radiometer or pyrheliometer, or a globe thermometer.

(g) *Globe Thermometer (G).* The Vernon Globe Thermometer consists of a 6-inch hollow copper sphere, with a 0.022 inch thick wall, painted matte (flat) black on the outside, and contains a temperature sensor like that of an unshielded dry-bulb thermometer with its bulb, or an equivalent, at the center of the sphere. A Vernon globe requires about 20 minutes to achieve equilibrium. Smaller globes, from 1.64-4.0 inch outside diameter, have been developed which have shorted equilibrium times; however, few have been demonstrated to be equivalent with a Vernon Globe. Globe thermometers are required in the assessment of thermal stress because they integrate radiant heat exchange and convective heat loss into a single value.

(h) *Wet-Bulb GIobe Temperature* (WBGT) *Meter*, also known as the Heat Stress Meter, is a compact electronic instrument that independently measures the dry-bulb, wet-bulb and globe temperatures. The instrument displays each of these values as well as computes and displays the WBGT Index value (described in Section IV). The approved Navy Heat Stress Meter (7G-6685-01-055-5298) is lightweight, self-contained, and equipped with a rechargeable power supply. A ventilating fan is included, in the shielded dry- and wet-bulb sensor assembly, to obtain aspirated wet-bulb temperatures. The entire unit can be adapted for remote monitoring and recording. Use and maintenance of the Navy's Heat Stress Meter is described and portrayed in the Navy educational film "Care and Use of the Heat Stress Meter" (35335-DN). Use of other electronic and

Figure 3-1. —Psychrometric Chart.

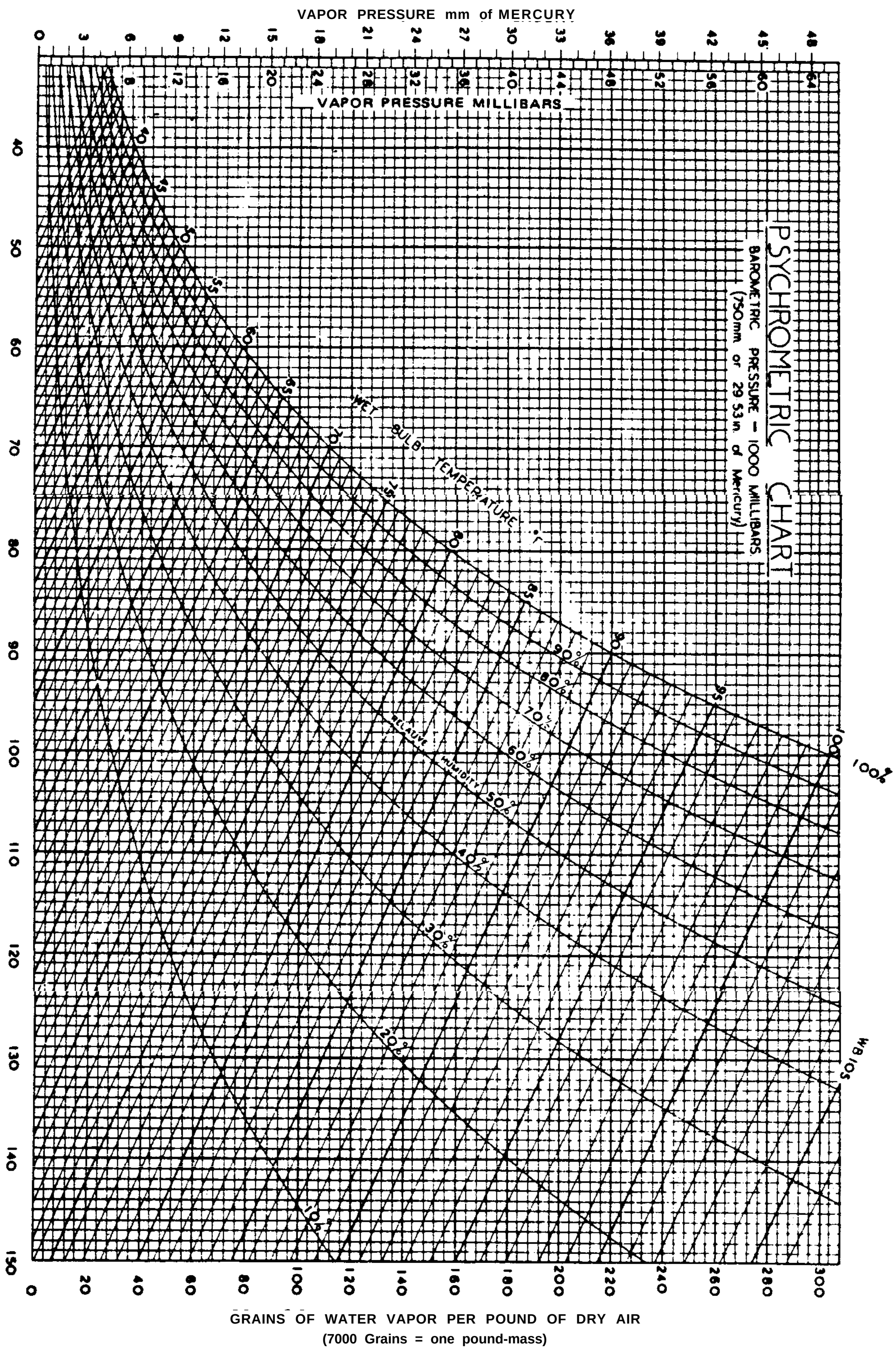

Figure 3-1.—Psychrometric Chart.

manual heat stress monitoring devices, other than a motorized psychrometer, are not approved for shipboard purposes unless the proposed devices meet the accuracy and response time test accuracy tolerances given in Table III and Figure 3 of Navy Procurement Specification 0513487126-SGA of 20 May 1987. No manual "heat stress monitors," which supposedly provide dry- and wet-bulb and globe temperatures and/or a so-called facsimile of the WBGT Index, are approved for shipboard uses due to inherent measurement errors over the wide range of thermal environments that exist throughout Navy ships. Special heat stress survey teams, from shore activities, should employ the most reliable, accurate equipments available. Inquiries regarding approval for shipboard use and for comparative purposes should be brought to the attention of MED-22. Naval Medical Command approval for shipboard uses can only be considered after receiving and evaluating a diversity of comparative data for each type of proposed alternative heat stress monitoring device.

Stock numbers for the Navy approved WBGT Meter, accessories kit, globe assemblies alone and rechargeable batteries, as of May 1988, are:

(a) WBGT Meter 7G-6685-01-055-5298 (Shipboard AEL 2-870003051)

(b) Accessories (spare sensor/wind tunnel assembly, globe, wicks, etc.) 9G-6685-01 -055-5299 (Shipboard APL 100110001)

(c) Globe Assemblies 9G-6665-01-149-8635

(d) Standard Nickel-Cadmium Rechargeable AA Batteries 9G-6140-00-449-6001

(i) *The Infrared Thermometer* (self-contained electronic) is used to measure the temperature of infrared energy emitted from various sources. The practical aspects of an infrared thermometer are that no contact with surfaces is required. In industrial settings, a lightweight, hand-held infrared thermometer allows scanning of surfaces to detect the functional adequacy of insulation, as well as to check overheating of equipments. Analog and digital readout and imaging devices are commercially available. In all applications, extreme caution should be exercised in using infrared thermometers. A number of such devices require the instrument to be four feet or more from the infrared sources to avoid infrared "flare". Electromagnetic radiation "flare" will result in erratic values, leading to misinterpretations of the data.

(j) *Effective Temperature* (ET) is an empirical sensory index, combining into a single value the effects of temperature, humidity, air velocity and thermal radiation. Combinations of conditions which produce the same subjective feeling of warmth in reference to still air are assigned the same effective temperature.

(k) *Equivalent Temperature is* commonly known as "Wind *Chill"*. As noted by Burton in 1955, "Wind Chill" lacks a scientific basis. The product of calculating "Wind Chill" is a heat transfer factor, and the relationship of temperature and air movement provide the derived heat transfer. The temperature—air movement relationship is known as the *Equivalent Temperature. (See* Article 3-14)

(1) *The Mean Radiant Temperature* (mrt) of a nonuniform environment (e.g., walls, overhead, deck and objects of different emissivities and at different temperatures) is defined as the temperature of a uniform black enclosure in which a solid body or an occupant would exchange the same amount of radiant heat as in the given nonuniform environment. It is estimated from dry-bulb and globe temperatures and air movement and is useful in determining radiative heat transfer (net gain or loss) relative to humans. Section IV provides further information on mean radiant temperature.

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Section II. DESIGN OBJECTIVES

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3-3. Objectives of Heating, Ventilation and Cooling

(1) Major objectives of heating, ventilation and cooling include maintaining physical fitness, mental alertness, fighting ability and the general well-being of personnel in the performance of their duties ashore or afloat. This should include consideration for the stresses of watches, prolonged cruising and battle or general quarters situations. The design and maintenance of environmental control systems should assure useful productivity and recovery from undue physical stress rather than thermal comfort alone.

(2) In addition to temperature considerations, environmental control systems must assure that the air in confined spaces contains sufficient quantities of oxygen and no harmful components.

(3) Special use areas such as selected Medical Department spaces, and those containing equipment and materials which require individually controlled surroundings, must be designed to guarantee optimal mission performance under variable environmental conditions.

Designs must address exhaust of gases and vapors which are heavier than air, therefore, in both shipboard and ashore applications, exhaust ventilation is required nine inches from the deck. Furthermore, just because the design supply air volumes and exhaust volumes meet design specification, optimal distribution within the space or the work site must be assured.

3-4. Heating

(1) In designing a heating system ashore, the relatively narrow range of climatic conditions in a given locale can usually be anticipated and the system designed accordingly. This sort of planning is obviously difficult for naval vessels on which heating systems must be designed to provide for a wide range of climatic conditions from arctic cold in winter to tropical heat in summer. The need for design flexibility is further extended by variable requirements for space, weight and power sources. In addition, the distance of the heating (or cooling) unit from the point of delivery must be considered. For general purposes in cold weather, the amount of heat supplied should be planned to balance heat loss when the outside air temperature is 10 F DB and the sea water temperature is 28 F, the air temperature at normal work stations should be sustained at least to 65 F.

(2) Aboard ship the conventional approach for heating is accomplished by drawing fresh outside air over heating coils and discharging the heated air into various compartments where it is required. In order to avoid condensation of moisture on and inside the air ducts and to provide a flexible heating system, outside air is initially preheated to 42-50 F DB. The air is then heated to the desired delivery zone temperature and distributed to the various compartments and spaces within that zone. A “heating zone” is defined as a group of adjacent spaces with approximately the same heating requirements.

(3) A zone temperature of 70 F DB is required aboard surface vessels for berthing, dressing, lounge, messing, medical, dental, office and control spaces. No effort is made to maintain a controlled moisture level in these spaces during cold weather; therefore, Medical Department personnel should anticipate increased symptoms associated with the drying of respiratory membranes among individuals working in these areas.

(4) Heating designs for submarines differ from those of surface vessels in that they provide a regulated humidity for the living and control spaces noted above. Symptoms associated with the drying of the respiratory membranes may be less pronounced than those noted aboard surface vessels. The heating design for submarine berthing, dressing, lounge, messing, medical, dental, office and control spaces should adhere to the following specifications: dry-bulb 79 F, wet-bulb 59 F, relative humidity 50% and WBGT Index 63 F.

(5) With the exception of the above noted living and control spaces and areas containing engineering propulsion components, inside working spaces should be maintained at approximately the given temperatures for purposes of efficiency and comfort of personnel. In those cases where atmospheric heating and cooling needs of the individual cannot be met there is the added problem of adding or removing protective clothing; all normally worn clothing must be viewed as protective in nature when considering the potential hazards aboard ships and ashore.

3-5. Ventilation

(1) The purpose of ventilation is to remove toxic substances, offensive odors and excessive heat and moisture, and to provide an adequate oxygen supply. Naval ventilation should be designed not only to prevent conditions aboard ship which could lead to acute overheating, but also to maintain an atmosphere conducive to the physical and mental efficiency of personnel. Ventilation of work spaces must be adequate to control toxic substances such as; solvents (e.g., perchloroethylene in dry cleaning plants, PD-680 Type II as a degreaser, etc.), fuel combustion gases (e.g., “stack gas” in firerooms), fuel vapors (e.g., fuel pump rooms, firerooms, auxiliary machinery rooms), hydrogen sulfide in CHT pump rooms, etc. *Ships with conventional ventilation system shall have the capability to electrically secure ventilation to prevent ingestion or spread of NBC contamination within the ships.* In 1983 Navy policy was established that the Circle William material condition must not be set for longer than 5 minutes in machinery spaces during training evolutions. The ventilation systems in ships with Collective Protection Systems (CPS) shall provide clean, filtered air within the CPS zones.

Ventilation systems must be as flexible as those designed for heating. Hot weather cooling of given spaces by ventilation should be planned so that the temperature within those spaces will remain below specified limits. These limits are determined, using as a base the highest anticipated hot weather (outside) temperatures. For general planning purposes the design weather conditions are 90 F DB, 81 F WB and 85 F sea water temperature. Special considerations must be made for external ambient environmental conditions in the Persian Gulf; these design weather conditions are: 105 F DB, 95 F WB and up to 90 F sea water temperature.

(2) Air circulation within manned compartments must be sufficient to eliminate “dead spaces”. An adequate air exchange will insure the removal of odors and will prevent the accumulation of moisture on surfaces of the spaces. Ventilation exhaust from sanitary spaces, food preparation and dining areas, sculleries and garbage disposal areas must not be recirculated or introduced into any other spaces. Ventilation of food preparation, laundry, dry cleaning and propulsion spaces must be balanced to provide a *negative* pressure within those areas, i.e., allowing for a net flow of air into the spaces. Propulsion spaces should have exhaust at 115070 of supply air in 600 pound per square inch (psi), gas turbine and diesel propulsion plants and aircraft carrier machinery spaces; exhaust 125% of supply in all other 1200 psi propulsion plants.

(3) Cooling by *ventilation is* a process of diluting

inside air with cooler outside air. It has proved to be of value aboard ships in reducing excessive temperatures in manned spaces. In those cases where steam and water leaks are minimal, negative pressure ventilation may partially offset the *adverse impact of high temperatures* upon personnel. However, as the ventilation systems of ships deteriorate it is unlikely that ventilation alone will compensate for the increased environmental heat upon personnel. To achieve optimal exhaust ventilation in machinery spaces the size of the screens over the exhaust uptake ducts should be 1½ inch grid mesh, and the ventilation systems must be maintained at optimal capability. In other spaces within a ship the exhaust uptake ducts of nine inches or less across should have ½ inch grid mesh; if the exhaust uptake ducts are greater than nine inches across the screening must be 1½ inch grid mesh. It should be evident that usually it will not be possible to cool spaces to needed temperatures by ventilation alone; although this is the general practice in engineering machinery spaces.

3-6. Mechanical Cooling

(1) Mechanical cooling and dehumidification of air is accomplished by passing incoming air over coils and fins cooled with a suitabIe refrigerant. As the warm humid air circulates over the coils, it loses heat and the moisture condenses on the fins. The conditioned air is then circulated through a ducting system to appropriate spaces and compartments. Cooling coils may be located in an air supply duct with the refrigerating unit and fan placed remotely, or the entire apparatus may be assembled into a single unit.

(2) Air-conditioning is frequently required in spaces containing precision instruments which are sensitive to extremes of temperature and humidity. Appropriate filtering of air will assure air purity within tolerance limits for equipments and personnel working in the spaces.

(3) Mechanical cooling is a current feature of the living areas and office spaces of combatant ships and most auxiliaries. Basic medical areas are air-conditioned; this is done to improve the recovery of patients, which takes precedence over the customary space and weight limitations aboard ships.

(4) “Cold shock” may be produced when personnel pass from heated areas into air-conditioned spaces. Individuals experience a rapid loss of body heat due to an increased evaporation of sweat from wet skin and damp clothing. Chilly sensations and shivering are common manifestations. A corollary is seen in persons who move into outdoor heat from excessively cooled environments. Personnel in this situation experience sudden dilation of superficial blood vessels and flushing. “Cold shock” and its thermal counterpart may be minimized by regulating air-conditioned spaces so that the differential temperature between those areas and heated or outdoor environments does not exceed 15 F DB. Medical personnel should be alert to the occurrence of these phenomena in individuals who work in the daytime heat of natural environments or the high temperatures of engine rooms, firerooms, galleys, laundries, etc. Persons entering cold rooms (e.g., walk-in freezers, cold storage boxes, cold test chambers, etc.) need protection from “cold shock”; protection can be achieved by the temporary use of suitable clothing or limiting the frequency and duration of exposures. (Also see NAVMED P-5052-29)

3-7. Additional Considerations Aboard Ship

(1) Excessive moisture may be generated in multiple shipboard conditions. In firerooms and engine rooms steam and water leaks are common sources of increased water vapor. Inadequate steam exhausting from dishwashers creates a high moisture content in sculleries and in the air of passageways adjacent to sculleries. Water vapor in the air is increased by the evaporation of sweat from the human body. Individuals performing heavy work in a warm to hot environment may lose as much as 1.5 liter (1.6 quarts) per hour in evaporated sweat. More sedentary personnel may lose 0.2 liters (200 ml., 0.2 quarts) of sweat per hour in hot spaces. Air-conditioning and dehumidification are the only effective ways to sufficiently adjust the ambient moisture content of living and working spaces; cooling by ventilation alone results in humidity that is always above that of outside air.

(2) Mechanical air supply and exhaust systems are provided for most working and living spaces; the quantity for each should be balanced respectively within the major sections of a ship. Ventilation of spaces in which excessive heat or undesirable odors are produced (firerooms, engine rooms, galleys, laundries, heads, etc.) requires a special design in order to provide a greater volume of mechanical *exhaust* than supply *(negative pressure);* this maintains an induced air flow *into* the compartment and prevents the spread of heat and odors to adjacent spaces. Compartments used for living, berthing, etc., should be provided with a greater volume of mechanical *supply* than exhaust *(positive pressure)* in order to maintain an induced air flow *out* of the space and thus prevent the entrance of possibly contaminated air from adjacent spaces.

(3) Ventilation and air-conditioning designs for living compartments, recreation spaces, mess decks (excluding serving lines), sick bay and inpatient wards, operating rooms and intensive care spaces, administrative areas, control, and all operating electronic spaces aboard surface vessels encountering the hot-weather outside temperatures of 90 F DB and 81 F WB (design limits, Article 3-5) or higher should favor conditions that optimize recovery from heat stress and maximize performance in hot and subtropical climates. The upper thermal design limits within the above noted spaces should be 80 F DB, 68 F WB, 55% RH (14.3 Torr VP), with 72 F WBGT (as ET). For comparable spaces aboard submarines the design limits should be slightly lower in terms of moisture content of the air; 80 F DB, 67 F WB, 50% RH, with 71 F WBGT (as ET).

(4) A preferred WBGT temperature of 78 F applies to prescribed hot-weather operational conditions in: laun-

dries, galleys, sculleries, passageways not open directly on weather decks, and food serving lines. However, the upper thermal physiology shipboard heat stress design environments should not exceed that given in Table 3-1. Aboard submarines the overall demands within the vessel should preclude the environmental conditions reaching 78 F WBGT during normal operations.

(5) Fireroom and engine room spaces require a special application of the method of cooling spaces with outside air. Frequently so much "wild heat" is produced and uncontrolled that it is neither practical nor feasible to reduce the temperatures within the *entire* space to the point of maintaining high physiological efficiency without unique engineering techniques. Some ships have control booths in the propulsion spaces, the recirculating air-conditioning units for these booths need to be designed to permit ready access for frequent cleaning. Outside of the control booths, and aboard those ships without control booths, personnel must have immediate access to spot cooling. Spot cooling is effected by delivering outside air at high velocity via ventilation ducts to the respective watchstander's stations. By this method a "cone" of air is provided to watchstanders, even though the Effective Temperature outside the "cone" of air is very high.

Misconceptions have evolved regarding spot cooling, it has been widely believed: (1) that air velocities of 2,000 fpm or more at a supply terminal provides *optimal* spot cooling; (2) that increasing the volume of air flow through a fireroom or engine room will automatically reduce the level of heat stress at watch stations; and, (3) that in a very hot space the watch standers will be kept cool by putting their heads up to or just inside a supply terminal. In reality, the key element in spot cooling is not high velocities of air flow at the supply terminal but an *optimal effective air velocity flowing over the worker.* This can be best accomplished by positioning the supply terminal so as to assure a direct, unobstructed air stream at an equitable distance from the individual.

Figure 3-2 illustrates the relationship of air flow over workers versus the *Percent Optimum Cooling* achieved by the air flow. It can be seen that approximately 72% optimum cooling is achieved at 250 fpm air movement, 82% at 500 fpm, 90% at 750 fpm and 100% at approximately 1500 fpm; air flows over the worker which exceed 1500 fpm result in a rapid decrease in the percent optimum cooling of the worker in a hot-humid environment. The very high air velocities cause turbulence and friction at exposed skin surfaces, which in turn, leads to heating of the skin and drying of the eyes and respiratory membranes. Unless the increased air flow is needed for engineering purposes, it is uneconomical to increase the air flow six-fold (from 250 to 1500 fpm) to obtain the remaining 28% optimum cooling. Furthermore, when air velocities over workers are 2,000 fpm or higher the percent optimum cooling will have dropped to 36% or less. The reason that percent optimum cooling is essentially O% at 47 fpm air flow is due to the natural "chimney effect" associated with standing man.

(6) Radiant heat control is essential relative to the worker. In the design of shipboard spaces which have radiant heat sources it is necessary to insulate the radiating surfaces wherever possible. In those situations where metal surfaces cannot be insulated, they should be painted with a low emissivity paint (emissivity less than 0.4). Thermal insulation should have the lowest possible thermal conductivity (k) value. The insulating material should be well-fitted together, should be of proper thickness for the source temperature, should be kept intact, and protected by metal sheathing where high traffic and abuse may occur. A reflective aluminized outside surface of thermal insulation pads will reduce radiant heat transfer into the space. In all cases, thermal insulation should be kept dry to remain effective; which requires that steam and water leaks must be eliminated. Merely reinsulating radiating surfaces without first correcting the steam and water leaks leads to frequent replacement of insulation.

Commercial industry statistical data, from multiple samplings, show that the lowest k values for given densities of thermal insulation are achieved with ceramic *(refractory)* fiber insulation, as compared with fiberglass. Commercially available ceramic fiber at 8 pounds per cubic foot density has a lower k value than fiberglass insulation at 11 pounds per cubic foot density; where both insulating materials are of equal thickness. The lower the k value results in lower surface temperature and lower radiant heat transfer, furthermore, the ce-

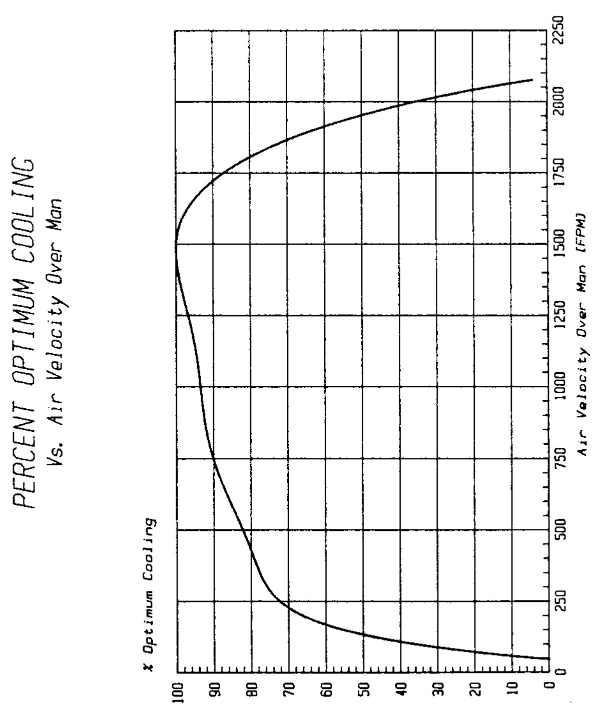

Figure 3-2.

ramic fiber insulation is lighter by approximately 3 pounds per cubic foot. Until recently, the use of ceramic fiber insulation aboard Navy ships was only permitted at temperatures above 850 F. Military Standards MIL-I-23 128 and MIL-STD-769 were revised, 1982 and 1983 respectively, to permit use of ceramic fiber insulation on machinery and piping surfaces below 850 F. At the present time, all airborne thermal insulation materials should be considered as potentially health hazardous.

(7) For many years the design of firerooms and engine rooms was based on equipment failure due to overheating and the potential of heat transfer of excessive heat to adjacent compartments. It was believed that workers could adapt or become "acclimatized" to the high levels of heat. *These concepts have been proven erroneous; the limiting factor is the worker not the equipment.* The physiological capability of workers cannot be altered to tolerate excessively hot-humid and hot-dry shipboard spaces, therefore, it is essential to design such spaces to permit personnel to perform their watch standing and equipment maintenance safely. Table 3-1 is the Thermal Physiology Design Criteria based on advanced, integrated technology. Allowances must be made for sufficient thermal recovery periods in thermal conditions similar to that noted in Article 3-7(3). Even with the exposure and recovery thermal design criteria given herein, mental impairment of workers maybe detectable after the first third of the respective exposure times. The environmental conditions for recovery must permit at least 6 hours of uninterrupted sleep per 24 hours. The thermal design limits given in Table 3-1 apply to *acute (short term) exposures only. No* definitive information exists at this time relative to the physiological effects of long term (repetitive exposures over a number of years) exposures in hot-humid shipboard spaces; however, one can assume that repeatedly exceeding the physiological limits of man is not conducive to the long term physiological well-being of the worker. (See Article 3-12.(8) regarding exceeding the PHEL values)

(8) The need for keeping the ventilation systems clean cannot be overemphasized. It has been estimated that a large naval vessel may take in as much as several tons of dirt a day into its ventilation system. Most of this is composed of fine, particulate matter which passes through filters but accumulate within ducting in high moisture environments. A significant amount accumulates on the filters, screens, heaters, fans and cooling coils and thus reduces the system's capacity for delivering the rated quantity of air. In order to obtain the maximum ventilation from existing equipment, all ventilation equipment should be cleaned and maintained on an established schedule. Use of a single layer of "cheese-cloth" may be used such as in galleys and laundries provided the cloth is changed frequently and dirt is not allowed to buildup. Maintenance of sufficient supply ventilation to control heat stress within a space should be given priority over the use of "cheese-cloth" over supply terminals.

Table 3-1. Summary of Thermal Physiology Heat Stress Design Conditions for Surface Vessels*

SPACE/LEVEL		Thermal Values At Actual Work Sites*			
		Dry-Bulb [F]	Wet-Bulb [F]	Globe [F]	Effective Velocity** [FPM]
PROPULSION SPACES: (NON-GAS TURBINE)					
Upper Level	4 Hrs	107	86	115	250
	6 Hrs	102	83	106	250
	8 Hrs	98	79	105	250
Lower Level	4 Hrs	98	84	108	250
	6 Hrs	92	81	100	250
	8 Hrs	89	78	96	250
PROPULSION SPACES: (GAS TURBINE)					
Upper Level	6 Hrs	98	85	100	250
	8 Hrs	93	82	97	250
Lower Level	6 Hrs	97	83	100	250
	8 Hrs	91	81	94	250
CATAPULT LAUNCH CONTROL ROOMS:					
	8 Hrs	92	80	97	250
LAUNDRIES:	4 Hrs	96	85	103	250
SCULLERIES:	3½ Hrs	92	83	94	250
GALLEYS:					
Food Prep. Area	4 Hrs	86	72	92	150
Food Serving Area	3 Hrs	86	77	94	150

*During normal work, excluding emergency or casualty control work rates. Environmental design conditions apply in work areas regardless of external ambient weather and sea water temperatures.

3-8. General Considerations Ashore

(1) Although the Navy has promulgated sound work practices for hot environments in its preventive medicine manuals for many years, they were directed primarily toward military personnel As a result of the Navy's Occupational Safety and Health (NAVOSH) Program, it is appropriate for the basic principles of heating, ventilation and cooling, contained in this chapter, to be applied to both military and civilian workers ashore and afloat. Implementing sound hot weather practices should be done in accordance with thermal conditions given in Table 3-2.

(2) The WBGT threshold values illustrated in Table 3-2 are needed for identification of heat stress levels at which *sound systemic heat injury preventive measures should be instituted.* They are based upon the hottest 2-hour period of a day ashore. The various preventive measures are given in Section III. *These threshold 2-hour exposure WBGT values must not be confused with the Physiological Heat Exposure Limits (PHEL) that apply to the exposure limits of workers in hot environments. WBGT threshold values apply to situations where sound preventive measures must be instituted; PHEL applies to safe physiological limits for exposures.* PHEL applications are discussed in detail in Section IV of this chapter.

Table 3-2. Recommended Threshold WBGT Values For Instituting Sound Hot Weather Practices

Work Load	Threshold 2-Hour Exposure WBGT (F)
Light Work (time-weighted-mean metabolic rate of 82 KcaI*m $^{-2}$*hr $^{-1}$)	86
Moderate Work (time-weighted-mean metabolic rate of 104 Kcal*m^{-2}*hr $^{-}$1)	82
Heavy Work (time-weighted-mean metabolic rate of 125 Kcal*m $^{-2}$*hr^{-1})	77

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Section III. PHYSIOLOGICAL PRINCIPLES

Article
Effects of Heat 3-9
Effects of Cold 3-10

3-9. Effects of Heat

(1) *General Effects.* Heat stress and heat strain have both immediate and long-term effects on humans. The immediate effects are a significant loss of performance, efficiency and loss of duty time due to systemic heat injury. Generally, the long-term effects of heat stress and strain arc not as apparent as the immediate effects. Prolonged exposure, however, is viewed as contributing to:

(a) Progressive loss of performance capability.

(b) Increased susceptibility to other forms of stress.

(c) Reduced heat tolerance.

(d) Potentially increased physical disability compensation.

(2) *Heat Balance Equation.* In order to understand the interaction between man and a heat stress environment, it is necessary to examine the concept of the empirical "Heat Balance Equation;" which is given as:

$$M \pm R \pm C - E = S$$

where; M = metabolic rate or heat production of man
R = radiative heat gain to or loss from man
C = convective and conductive heat gain to or loss from man
E = evaporative cooling
S = heat storage in man

Man's internal heat (M) is produced by basic metabolic function and heat of variable physical activity (work). In the "Heat Balance Equation" this factor (M) always results in a positive value; to be a living body the function of metabolism must occur, therefore, heat will be produced. Heat transfer by radiation (R), convection and conduction (C) between man and its environment may result in a positive or negative heat balance. For example, if the environment is cooler than man a *negative* (toward the environment) *heat balance will* result. Conversely, when the environment is warmer than the subject, a *positive heat balance* (toward the subject) results. If uncompensated, this latter state results in excessive heat storage and leads to the various physiological states we recognize as "heat strain". Loss of body heat by evaporation (E) is the fourth means by which man is able to maintain thermal equilibrium. Evaporation by sensitive and insensitive perspiration results in cooling of the body surface. Evaporation does not occur when the partial vapor pressure of water in the environment equals that of the body surface. Further, if the partial vapor pressure of water in the environment exceeds that of the skin, environmental moisture condenses on the skin with a resultant positive conductive heat transfer by no evaporation. Evaporative heat loss from the respiratory mucosal surfaces is minimal, representing perhaps only 2070 of the matabolic heat (M).

(3) *Thermoregulatory Mechanisms.* Body heat is regulated by a complex interactions of physical environmental factors (temperature, humidity, air movement, radiant heat, etc.) and the physiologic and behavioral response of the subject. The skin surface is the primary

site of heat exchange between the body anti the surrounding environment. Thermoregulation is mediated by circulatory (e.g., central and capillary blood flow), neural (e.g., hypothalamic, autonomic pathways), and biochemical (e.g., ionic and endocrine) functions involving central or peripheral levels of response and by individual behavioral variants. If man is to compensate for environmental heat stress, this intricate physiologic network must remain functionally intact. The degree and reversibility of heat strain in any given case is directly related to the duration and severity of the disturbance of mechanisms for heat regulation.

(4) ***Failure of Thermoregulation.*** When temperature balance mechanisms for the body fail, spiraling of body temperature is initiated. Heat storage increases; skin and deep-tissue temperatures rise; cardiovascular, respiratory and metabolic functions accelerate; and, renal function is depressed. Increased metabolic heat pushes the cycle faster to the point of cardiovascular and renal failure and irreversible damage to the nervous system and muscular tissues. The cycle can be broken only by timely and definitive therapy.

(5) ***Acclimatization.*** Physiologic response to heat stress has been treated thus far as a rapidly occurring process with decompensation resulting in relatively immediate damage or in cumulative injury over a more prolonged time period. ***Under more favorable thermal conditions,*** the body can "acclimatize" or adapt to environmental heat stress. Until 1971 it was accepted that acclimatization to heat stress could be descriptively characterized by near normalization of heart rate and skin and rectal temperatures during 4 to 6 days of successive heat exposure. In addition, sweat production during adaptation was expected to increase to levels of 1.5 or more liters per hour. In 1971 Navy medical researchers indicated that these parameters were inadequate to describe acclimatization accurately; the research indicated the earlier studies were premature in the assessment of heat acclimatization on consecutive days, as a number of other physiological parameters had not reached an adapted state. Using both untrained and trained test subjects, the studies extended exposures out to 90 days. It was learned that heat acclimatization was only 78% complete after 14 consecutive days of work in hot-humid heat.

Application of advanced criteria for optimum heat acclimatization revealed, when personnel were previously trained to perform moderate physical work without physiological strain in a thermally neutral environment, that various body systems adapt at different rates. Table 3-3 illustrates the percent achievement of optimum heat acclimatization for 13 physiological parameters at 4 time intervals of consecutive days exposure while performing moderate physical work. Overall optimum heat acclimatization to hot-humid conditions of 95 F DB, 88 F WB and air movement of 100 fpm was achieved in 22 consecutive days of heat-work exposures.

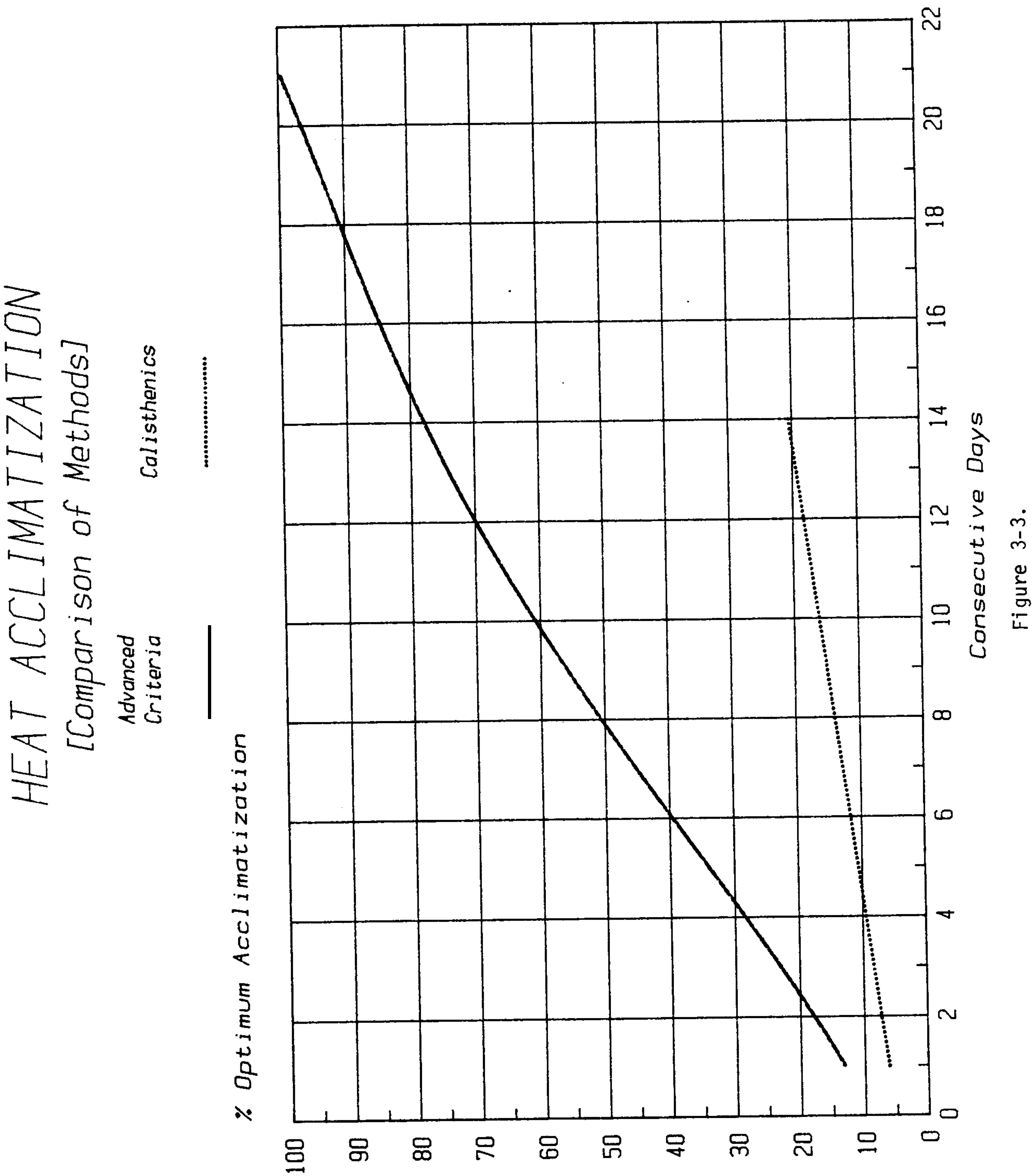
As can be seen in Figure 3-3, the rationale prior to 1971 overestimated how much heat acclimatization could be achieved in time periods as short as one week. In 1976 the findings of the Navy medical researchers were borne out by a research team in South Africa, who comprehensively studied energy exchanges, body temperatures, sweating, cardiovascular adjustments, body fluid adjustments, body weight deficits and circulating protein changes. Clearly, there are 3 distinct stages of acclimatization, of which the third stage begins after the seventh consecutive day of inducing heat acclimatization.

Special consideration must be given to various other factors. Heat acclimatization is not applicable to overall heat stress levels indicated in Table 3–2; thus, personnel working in areas such as firerooms, engine rooms, laundries and steam catapult launch control rooms should not be expected to adapt physiologically to their environment. In order to achieve maximum benefits from acclimatization, *it is extremely important that moderate (more than sedentary) work be performed during the adaptation process.* Even fully acclimatized personnel are rendered more susceptible to heat injury in the event of excessive fatigue; alcoholic intoxication; acute infectious disease; obesity; inadequate water, salt or caloric balance; and the use of medications containing belladonna alkaloids. The rate of achievement of heat acclimatization is *retarded by the use of commercially prepared electrolyte-type beverages as well as supplementary sodium chloride ("salt"] in excess of* 2

Table 3-3. Percent Optimum Heat Acclimatization on Consecutive Days of Heat-Work Exposures for Physically Trained Personnel

Physiologic Parameter	Percent Achievement On:			
	Day 1	Day **7**	Day 14	Day 21
Rectal Temperature	6	38	**72**	100
Tympanic Membrane Temperature	6	37	**71**	100
Deep Esophageal Temperature	51	82	**93**	100
Mean Skin Temperature	80	93	**98**	100
Heart Rate	8	37	**67**	100
Systolic Blood Pressure	11	38	**56**	100
Diastolic Blood Pressure	7	36	**70**	100
Pulse Pressure	9	36	**63**	100
Mean Arterial Blood Pressure	4	35	**79**	100
Est. Total Vascular Resistance	8	37	**70**	100
Est. Cardiovascular Reserve	7	36	**69**	100
Sweat Rate	3	37	**76**	100
Urine Osmolality	3	39	**82**	98
Overall Percent Achievement	13	**45**	78	**99.6**

Figure 3-3.—Heat Acclimatization (Comparison of Methods).



grams per day, this is discussed in more detail in this section. Finally, a degree of stable acclimatization at any one level of heat stress does not guarantee full acclimatization to a higher level of heat stress.

(6) ***Heat Illnesses.*** There are various reasons why military populations are more prone to heat disorders. The constant influx of unseasoned and unacclimatized personnel into recruit training creates a potential for an increased incidence of heat illnesses. Following recruit training, exposure to a variety of environmental stresses can be expected, with little opportunity for prior adaptation. In combat situations, with mass movements of military units to tropical and desert climates, well trained personnel may be exposed to a higher level of heat stress. A common-sense preventive measure program, emphasizing moderate physical activity and general health maintenance, will lead to the early adaptation of physically fit personnel to the more stressful environment. Heat disorders have a world-wide distribution and may even occur in cold climates where metabolic heat production exceeds an individual's adaptive abilities. They may, in severe cases, be accompanied by changes in serum electrolytes (hyponatremia, hypochloremia, acidosis, hyperkalemia), urinary electrolyte concentrations (decreased sodium and chloride excretion, increased loss of potassium and hydrogen ions), proteinuria, increased consumption of protein, and coagulopathy (disseminated intravascular coagulation defects). Acute overheating may thus lead to numerous heat related illnesses. In order to describe expeditiously these diseases and their management, they have been consolidated into 4 basic categories, excluding local heat injury due to burns: (1) heat rash, (2) heat cramps, (3) heat exhaustion (including anhidrosis, salt-deficiency, water-deficiency, exercise-related heat exhaustion and heat syncope, and (4) heat stroke (including hyperpyrexia).

(a) ***Heat Rash.*** The clinical picture of heat rash (miliaria rubra) is too well-known to require description. It is prevalent among military populations living in hot climates or working in hot spaces ashore or aboard ship. It interferes with sleep, resulting in decreased efficiency and cumulative fatigue, and thus, predisposes the individual to heat exhaustion. Heat rash impairs sweating and decreases evaporative cooling on the skin surface; it may, therefore, favor the evolution of heat stroke.

(b) ***Heat Cramps.*** Heat cramps may occur as an isolated syndrome with normal body temperature or in conjunction with heat exhaustion. They are precipitated by the replacement of body water losses without concurrent replacement of sodium chloride deficits. Heavily sweating individuals drinking large volumes of water with insufficient salt replacement are particularly at risk. Heat cramps may be localized or generalized with recently stressed muscle groups, particularly those of the extremities and abdominal wall are most frequently involved. Minimal serum and urinary electrolyte changes, as well as hemoconcentration, may be observed but should not be expected. Clinically the patient usually exhibits moist, cool skin and normal or slightly elevated temperature. Muscular soreness (myalgia), a normal finding following heat cramps, must be differentiated from that occurring in association with rhabdomyolysis which is associated with necrosis of muscle tissue. Whereas salt depletion appears to be instrumental in the evolution of heat cramps, *"salt loading"* may be contributory in the pathogenesis of rhabdomyolysis. Therefore, until definitive evidence is available, *"salt loading"* should be avoided in the prevention and therapy of heat cramps.

(c) ***Heat Exhaustion***

(1) Heat exhaustion occurs as the result of peripheral vascular collapse due to excessive dehydration and salt depletion, however, the usual case involves dehydration and over-exertion during physical work. The syndrome is characterized by profuse sweating, headache, tingling sensations in extremities, pallor, dyspnea, palpitations associated with gastrointestinal symptoms of anorexia, and, occasionally nausea and vomiting. Neuromuscular disturbances with trembling, weakness, and incoordination coupled with cerebral signs ranging from slight clouding of the sensorium to actual loss of consciousness complete the picture. Heat cramps may be present. Physical examination reveals a mild to severe peripheral circulatory collapse with a pale, moist, cool skin and a rapid (120-200 beats per minute at rest), thready pulse. Systolic blood pressure will generally have been quite elevated (180 mm Hg or higher during work) prior to the onset of the illness, followed by a rapid drop while work continued, and within normal range by the time of examination; however, the wide ***pulse pressure*** during work will usually be decreased at the time of physical examination. The oral temperature may be subnormal (as in the case of hyperventilation being present) or slightly elevated. It is not uncommon to find rectal temperatures of heat exhaustion patients between 101-104 F, dependent upon the type and duration of physical activity prior to the overt illness.

(2) Heat exhaustion is an accepted clinical diagnosis and, as a classification of heat disorder, it constitutes the majority of reported cases of heat illnesses. However, from the standpoint of pathogenesis, heat exhaustion is not one but several entities. *Exhaustion or collapse in the heat can occur from physical work alone, even in the absence of dehydration or salt deficiency.* Nevertheless, in some cases, more frequently in unacclimatized personnel, water or salt deficiency is present to some degree and may be primarily responsible for the clinical picture. Once again the problem of body salt content arises. Figure 3-4 illustrates numerous interacting factors predisposing heat cramps, heat exhaustion, heat stroke and rhabdomyolysis (noted under "Heat Cramps"). Unless salt deficiency has been *clearly demonstrated by laboratory analysis* of serum or urine, one should be suspicious of *salt loading* if a reasonably normal diet has been maintained and supplementary salt has been taken indiscriminately. Prior to 1972 there were numerous reports indicating heat exhaustion patients having consumed between 6-24 salt tablets per 24 hours,

even when eating a well balanced diet. Since 1972 the Navy Medical Department placed use of salt tablets on a controlled basis, the high consumption of sodium chloride has been primarily limited to eating field rations without sufficient water intake (See "Salt and Water Intake" in Article (8)(b)(2) of this Section). All patients suffering an episode of severe heat exhaustion should be assigned light duty for 24-48 hours following their initial recovery. Should a patient experience additional bouts of heat exhaustion, a careful review of the medical history and working situation should be undertaken and corrective actions instituted. *Strong consideration should be given to personnel being more susceptible to recurrence of heat exhaustion or possibly heat stroke.* Recurrence of serious disorders are usually more severe than the preceding bout. It is believed that the susceptibility lasts, which requires affected personnel to be reintroduced into the work situations in gradual steps to determine their safe limitations. Documentation of the heat illness should be included in the individual's health record, details should be provided to guide followups or a clear history for future reviews.

(3) ***Heat Syncope*** is a familiar form of heat illness, not related to salt or water deficiency or to excessive physical work. This type of heat illness is typically seen in troops standing in parade formation in hot outdoor climates. It is the result of pooling of blood in dependent parts of the body and dilation of peripheral vessels. The disparity between vascular capacity and circulating blood volume leads to cerebral ischemia. Vagotonia may be a contributing factor.

PATHOGENESIS OF COMPLICATIONS OF EXCESSIVE PHYSICAL EXERCISE

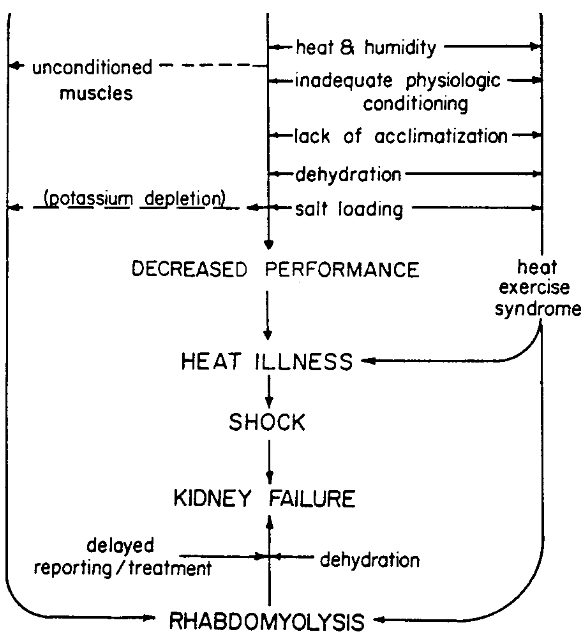


Figure 3-4.

(4) ***Anhidrotic Heat Exhaustion*** maybe the result of a preexisting dermatologic lesion (usually heat rash or sunburn) which interferes with sweat secretion. Personnel may not be aware of progressive heat intolerance associated with impairment or absence of sweating. Salt and water deficiencies are not prominent in this form of heat illness. Clinical examination reveals a warm, dry skin and an elevated deep body temperature, sometimes as high as 104–106 F. Exhaustion is present, but disturbance of consciousness is uncommon in the early stages of the disorder. ***Some*** individuals with the disorder may develop true heat stroke.

(5) When prompt first-aid is available, the mortality rate from heat exhaustion syndromes is extremely low. As a rule, removal of the victim from a hot environment to a cool area, rest and fluid replacement when indicated will satisfy the needs of all but the most severe cases of this disorder.

(d) ***Heat Stroke —*** HEAT STROKE IS A MEDICAL EMERGENCY and is associated with a potentially high mortality rate. Whereas *heat exhaustion* may be regarded as the end result of overactive heat-balance mechanisms which are still functioning, *heat stroke* results when thermoregulatory mechanisms are *not functional,* and the main avenue of heat loss (evaporation of sweat) is blocked. There may be prodromal symptoms of headache, malaise and excessive warmth, or a general picture of heat exhaustion. The onset is usually abrupt with sudden loss of consciousness, convulsions, or delirium. Sweating may or may not be absent in the typical case. Inquiry may reveal that the cessation of sweating was noted by the patient prior to onset of the other symptoms, however, with marked central nervous system (CNS) involvement (e. g., unconsciousness) this information usually comes too late. Since water intake may continue in the absence or reduction of sweating, overhydration rather than dehydration may occur. This is manifested by diuresis which is an added signal of impending disaster. During the early stages of this condition, after the body temperature has risen, the patient may exhibit euphoria. On physical examination the skin is hot, flushed and dry; in severe cases petechiae may be present. Deep body temperature is high, frequently in excess of 106 F. A rectal temperature exceeding 108 F is not uncommon and indicates a poor prognosis. The pulse is full and rapid, while the systolic blood pressure may be normal or elevated and the diastolic pressure may be markedly depressed (60 mm Hg or lower). Respirations are rapid and deep and simulate Kussmaul breathing. As the patient's condition worsens, cyanosis is usually noted together with a peripheral vascular collapse manifested by a rapid pulse and hypotension. The breathing becomes shallow and irregular. Pulmonary edema, incontinence, vomiting, hemorrhagic tendencies, disturbance of muscle tone, myocardial necrosis, menigismus, opisthotonos, jaundice, albuminuria, thrombocytopenia and prolongation of the prothrombin time may occur. Renal failure with rapidly developing hyperkalemia and azotemia is not uncommon. Death may ensue very rapidly, but if the patient survives until the second day, recovery chances improve. Rectal temperatures of 102-103 F may persist for several days during which time mental disturbances, excitement and delirium may continue or recur. Headache may persist for several weeks after the attack. In the first few days after the temperature has been reduced from a critical level severe relapses may occur. The patient should, therefore, be observed carefully during this period and rectal temperatures should be recorded frequently. Treatment, as outlined below, should be started again at the first indication of relapse. It is also important to emphasize that the heat regulating centers may be extremely labile for many weeks after an attack. One attack of heat stroke predisposes to a second attack, and care should be taken by the individual to avoid a second exposure to the precipitating condition. An alternative view is that the individual is a member of a susceptible population and remains susceptible. Careful documentation of all factors associated with the occurrence and treatment of this illness are essential.

(7) ***Treatment of Heat Casualties***

(a) ***Heat rash*** is best treated by keeping the skin dry for part of the day at least. Cooled sleeping quarters will remedy the situation and permit personnel to work in hot-humid conditions without developing heat rash. Calamine *lotion* may be useful under appropriate environmental conditions. When the environment or physiological climate does not permit the skin to remain dry for more than a few minutes a day, calamine *liniment* may offer some relief.

(b) ***Heat cramps*** are initially treated by relieving the severe pain and evaluating serum/urine chemistries for evidence of salt depletion. If such a deficiency exists, the administration of O. 1% or physiologic saline solution by mouth or physiological saline intravenously may be indicated. Care should be taken not to give excessive amounts.

(c) ***Heat exhaustion*** generally requires only rest in a cool place and adequate water intake. As in the case of heat cramps, saline solutions are indicated only when salt depletion has been documented in the laboratory. When physical exertion preceded the onset of heat exhaustion, and a salt deficiency exists, the judicious intravenous administration of physiologic saline or 5% glucose and saline may accelerate recovery. Recovery is usually prompt, but *immediate return to duty is inadvisable except in the mildest cases.*

(d) Anhidrotic heat exhaustion must be treated as if it is heat stroke. Prompt intervention is essential. Until the normal skin function can be restored the patient should not return to the environmental situation which precipitated the illness.

(e) Heat stroke is a MEDICAL EMERGENCY. Treatment principles are outlined below:

(1) ***Restore Normal Temperature.*** The body temperature must be lowered *promptly* to safe levels (rectal temperature 100-101 F). The more prolonged the hyperpyrexia, the greater is the threat to life; the hyperthermia accelerates metabolic heat production, causing the body temperature to spiral upward at an ever-increasing rate. In the field, the patient's clothing should be removed, except for underwear. If there is a source of cool water nearby, the patient should be immersed in it—otherwise water should be sprinkled over the patient and its evaporation hastened by fanning. In addition to these cooling measures, attendants should rub the victim's extremities and trunk briskly to increase the circulation to the skin. Arrangements should be made for the immediate removal of the individual to a hospital or properly equipped treatment facility; cooling measures should be continued during the transfer. Upon reaching the medical facility, the patient should be placed in a tub of water and ice. W bile in the ice-water the extremities should be massaged continuously as noted above. When the rectal temperature drops to between 100-101 F, the victim may be removed to a hospital bed. The rectal temperature should be monitored every 10 minutes until stable. Within the first few days of hospital treatment there should be careful observation for a relapse; the patient may readily become hyperthermic or *hypothermic.* It is desirable to maintain the rectal temperature between 100-101 F. Rapidly increasing temperatures can usually be managed with ice water sponge baths and fanning; precipitous drops in temperature may require the judicious use of warm blankets. Shivering, involuntary muscular activity, is undesirable because it accentuates tissue hypoxia and lactic acid acidosis. Again, the patient's rectal temperature should be monitored every 10 minutes during a hyperthermic or hypothermic condition.

(2) ***Drugs:***

(a) ***Sedative Drugs.*** Sedative drugs should be avoided if possible since by their depressive effect they may disturb central thermoregulatory centers. Restlessness can usually be controlled with gentle restraint. Sedatives are indicated in the treatment of convulsions. If a longer acting drug is needed, pentobarbital should be administered intramuscularly. Sodium amytal and morphine are contraindicated.

(b) ***Other Drugs.*** Atropine or other drugs which may interfere with sweating are contraindicated. Ephinephrine and other adrenergic drugs should not be used. However, when hypotension occurs accompanied by low cardiac output (elevated central venous pressure, congestive heart failure) isoproterenol (or dopamine) can be effective in improving cardiovascular dynamics. Intravenous administration of mannitol to induce osmotic diuresis may be useful where renal tubular necrosis is suspected. The use of aspirin, or like medications, is not indicated, since there is no evidence that it will lower body temperature in the noninfectious state. *Small doses of diazepam* (Valium— 10 mg) *may be administered intravenously to control convulsions as needed.*

(3) Intravenous Fluids. Parenteral administration of physiological saline solution in moderate amounts (1,000-1,500 cc.) may be indicated. However, *extreme caution must be exercised if a hyperthermic state exists;*

in a hyperthermic state the patient may appear hypovolemic but would be normovolemic in a normothermic state. Subsequent fluid administration must be determined by hourly urinary output and serum electrolyte determinations. Plasma volume expanders should be administered with caution if there is evidence of shock, especially if the patient is reasonably normothermic; a rapid pulse, of small volume, is an indication for considering their use. Care should be taken in the administration of parenteral fluids if there are signs of pulmonary congestion or rising central venous pressure. Close observation of the patient for renal failure is necessary. Rapidly developing hyperkalemia and azotemia necessitates hemodialysis or peritoneal dialysis.

(4) ***Venesection.*** Venesection is ineffective in treating the pulmonary edema which occurs with heat stroke.

(5) ***Oxygen.*** Oxygen may be desirable to combat tissue anoxia. Oxygen should be administered by face mask or nasal catheter if cynosis or pulmonary congestion is present. The use of a nasal catheter rather than a face mask is recommended if the patient has been vomiting, because of the danger of aspiration from the face mask.

(6) ***Other Complications.*** Spontaneous hemorrhage may occur as the result of hypofibrinogenemia or consumptive coagulopathy. Renal failure, pulmonary congestion and cerebral edema may complicate the clinical course. Details of therapy are beyond the scope of this manual. Readers are referred to current texts and technical papers on this subject.

(7) ***Disposition.*** All episodes of heat stroke should be fully documented and made a part of the patient's permanent medical record. Evidence suggests that serious physiologic damage may persist long after apparent recovery from heat stroke. Heat stroke victims may thus be more susceptible to recurrent episodes of heat illness under less intense conditions. *Heat stroke victims never be returned to heat stress similar to that which precipitated the illness without the approval of an appropriate medical authority (Medical Board).* A personnel heat injury report ("Heat/Cold Injury Report", NAVMED 6500/1) should be submitted to Commander, Naval Medical Command, Attention MED 22, Department of the Navy, Washington, D. C., 20372.

(8) ***Prevention of Heat Injuries***

(a) ***Engineering Control:***

(1) Engineering measures begin with adequate isolation or insulation of the principal sources of heat and humidity. Sound engineering practice should be maximum reduction of steam and water leaks, proper ventilation and maximum control of radiant heat. In some situations the source should be completely enclosed and connected to an exhaust. Special industrial settings may not permit the general atmosphere to be cooled by ventilation or mechanical means, therefore, isolation of the workers from the sources of heat must be practiced. When only a few workers are exposed in a large space, control can be accomplished by spot cooling and use of clothing which is unstarched and has good wicking characteristics, or by use of loose-fitting coveralls through which cool air is circulated. The latter also requires an unrestrictive air supply which provides clean, filtered breathing air. The temperature of air striking a worker within the spot cooling cone should not be less than 80 F; for continuous exposure the velocity should be approximately 250 fpm (See Article 3-7). Short exposures to higher velocities, below those associated with skin friction (about 1500 fmp), are sometimes beneficial in partially offsetting the presence of low levels of radiant heat. Workers can adjust their exposure by moving in and out of the spot cooling cone. Flexible ducts provide a means to regulate the location of spot cooling, thus avoiding excessive chilling of the head, shoulders and back. Engineering practice, however, should include proper positioning of supply terminals so that maximal effective air velocities may be obtained.

(2) Control of radiant heat is essential, in terms of economy in operating the systems as well as the well-being of personnel. As indicated in Article 3-7(6), thermal insulation should be well-fitted, no gaps, should be of proper thickness for the source temperature, should be kept intact and protected by metal sheathing where high traffic of abuse may occur. Furthermore, multiple layers of paint reduce the effectiveness of thermal insulation in controlling radiant heat. Snow white paint has an emissivity of approximately 0.9, whereas some highly buffed or polished stainless steels (e.g., Type 18-8, Allegheny metal No. 4 or No. 66) have emissivities from 0.11-0.16. The lower the emissivity of the outer covering the better the control of radiant heat. However, it must be noted that applying thermal insulation *over a low emissivity surface (e.g.,* pipes painted with low emissivity paint) does not effectively control radiant heat transfer from the insulation surface. The exposed surface emissivity is the important aspect of radiant heat transfer. On bare, uninsulated metal the application of low emissivity paints (with emissivities of 0.4 or less) will assist in controlling radiant heat transfer to the space. Since the Navy undertook major replacement of asbestos thermal insulation with soft (fibrous) fiberglass there were many complaints that radiant heat increased abroad ships. Part of the problem is associated with the quality of workmanship, but one cannot overlook the thermal conductivity (k) factors, densities and thicknesses of fiberglass replacement material. The lower the k factor of thermal insulation the better the control of radiant heat. Ceramic has a lower k factor at 8 pounds per cubic foot density than the fiberglass at 11 pounds per cubic foot density. Therefore, given equal thicknesses of ceramic ("refractory") fiber insulation and fiberglass, the ceramic fiber insulation is superior in controlling radiant heat. It is essential that the quality of all thermal insulation materials must be checked to ensure that specific characteristics of the materials are actually received to meet system design criteria. When extreme radiant heat is present, personnel should be protected by use of reflective devices (e.g., clothing or screens) and protection of hands, face and eyes. Also whenever personnel handle asbestos, fiberglass or ce-

ramic insulation materials, they should be protected; in particular their respiratory systems should be protected. Asbestos and fiberglass have been proven to be deleterious to the health of human, and recently ceramic fibers have been shown to be deleterious to the health of animals.

(3) In very special situations the use of vortex cooling garments may be used, but the objective liabilities may outweigh the subjective false sense of well-being which they impart; furthermore, as in the case of ***compressed*** air cooling, the air must be free of all possible contaminants (e.g., same quality standard of air used for diving). Other important preventive measures include an adequate number of showers for the workers, clean rooms for changing into dry clothes after work and a thermal environment with the design characteristics noted in Articles 3-7(3), 3-13(6) and 3-13(7).

(b) ***Medical Measures.*** Engineering methods are not always effective and often must be supplemented or preceded by medical measures. In physiologically compensable environments, performance in the heat can be improved greatly by proper selection and acclimatization of workers. In all hot environments, improved performance can be achieved by controlling fatigue, nutrition and alcoholic usage, and by periodic examination for underlying illness and the early symptoms of heat strain. The reasons for different persons developing different forms of heat illness are not clear. Until such information becomes available, every effort should be made to relieve excessive stress on each individual's heat regulating mechanism. The following measures will assist in reducing systemic heat injuries:

(1) ***Acclimatization.*** Heat acclimatization applies to those environments which permit physiological compensation such as outdoors, or in those indoors situations which are not excessively hot; for excessively hot indoors environments see Article 3-9(8)(b)(6). Heat acclimatization can only be acquired satisfactorily by working in a compensable hot environment over a period of time (See Article 3-9(5)). *Rapid acclimatization in raw recruits is impossible except under close medical supervision;* even then, it may be difficult to avoid some heat casualties. A "break-in" period of about two weeks, with progressive degrees of heat exposure and physical exertion will minimize the number of systemic heat injuries and improve productivity over a longer time period.

(2) ***Salt and Water Intake.*** (Medical personnel will find detailed information on salt and water requirements in NAVMEDCOMINST 6260.6 series.)

(a) Indoctrination of supervisory personnel in recognizing the need for liberal allowance of water will help abolish the false notion that men can be trained to resist dehydration. "Water discipline" must be replaced with the doctrine of "water freedom" in which drinking moderate amounts of cooled water at frequent intervals is encouraged.

(b) Maintenance of a proper salt content is of greatest importance, particularly to individuals in the early stages of heat acclimatization. The rationale used for many years was that large quantities of salt were being lost in the sweat and that the body was unable to manage physiologic conservation of salt. Thus, it had been widely assumed that large quantities of supplementary salt were necessary, and that excessive amounts would be excreted without harmful effects. Unfortunately, many deleterious side effects were ignored for years. The potential relationship of rhabdomyolysis and excessive sale loading (Figure 3-4) lead to extensive investigation of the relative value of supplementary sodium chloride intake by healthy young men (ages 19-3 1) during training and heat acclimatization. It was determined that:

(1) The current estimated "normal" dietary intake of sodium chloride in the general United States population is approximately 15 gms daily. This estimate includes the common practice of salt shaker supplementation prior to tasting of served food.

(2) Field rations contain a variable amount of sodium chloride, dependent upon the Federal Stock Number and the manufacture dates. Individual Combat Meals (FSN 8970-577-4513) manufactured prior to 1975 contain 22.1 gms of salt for those eating 3 meals per day, without using the salt packets. Individual Combat Meals of the same stock number but manufactured as of 1975 contain 9.0 gms of sodium chloride for three meals per day, without using the salt packets. Long Range Patrol Food Packets (FSN 8970-926-9222) contain 25.5 gms of sodium chloride, without using the salt packets. Individual Ready-to-Eat Meals, replacing the Individual Combat Meals noted above, contain 19.9 gms of sodium chloride, without using salt packets. Each sodium chloride (salt) packet contains 4 gms of salt, and up to 3 packets are provided per day. Therefore, it is possible to have an intake of 37.5 gms of NaCl per day. The high salt content of field rations is basically to preserve the food for a longer storage life.

(3) An individual's greatest need would occur during the combined stresses of initial physical training and heat acclimatization in a hot-humid environment without water restriction. However, judicious use of sodium chloride is recommended.

(4) The field grade salt tablets are 10 grain (0.648 gins; 0.255 gms of sodium and 0.393 gms of chloride) each.

(c) The investigative results to date suggest that the free use of supplementary sodium chloride or salt tablets is contraindicated under most conditions of heat stress. *Proper sodium chloride level can be achieved by providing adequate water a normal diet and a salt shaker on the table for conservative use, with no more than the equivalent of 2.0 gms of supplementary salt (preferably not salt tablets) per day.* Deviations from these recommendations must be governed by the past and present medical histories of individual workers and adjusted according to individual need by the Medical Department representative. There is clear evidence that use of commercially prepared electrolyte-type beverages reduce physiologic performance. Furthermore, supplementary sodium chloride produces a 20% reduction of the optimal work capacity of personnel in the heat, reduces the rate of achievement of optimal heat acclimatization and alters cardiac function. There are numerous deleterious physiologic changes which increase the risk of incurring heat illnesses when more than 2 gms of supplementary sodium chloride is ingested per day in hot environments. Use of supplementary sodium chloride must be based upon the medical history and current physical status of each individual.

(d) Water intake requirements are a function of work performed, the level of heat stress and the amount of salt consumed. Figure 3-5 shows the relationship of liters of water intake required as a function of heat stress, physical work and a "normal diet" sodium chloride intake of 15.0 gms per day. Figure 3-6 shows the same relationships but for 25.5 gms of sodium chloride per day with the Long Range Patrol Food Packet (FSN 8970-926-9222). In both Figures, no supplementary salt (salt packets) have been taken into account. The water requirements in both Figures need to be increased by 1 liter per day for every 6 gms of sodium chloride (e.g., 2 liters per day for 3 salt packets (12 gms of NaCl) per day in field rations).

(3) ***Special Programs.*** A program of special training schedules for obese personnel and other groups suspected of heat susceptibility will reduce systemic heat injuries. Training supervisory and administrative personnel should be taught to recognize the signs and symptoms of excessive heat strain and impending heat stroke and heat exhaustion in these men.

(4) ***Clothing.*** Clothing should be worn loosely at the neck, and at the cuffs of sleeves, and at the bottom of trousers to facilitate convective cooling. Some synthetic clothing materials interfere with evaporative cooling, although they may subjectively feel cooler. Poplin or other high natural fiber content clothes have good "wicking" characteristics and are superior materials for evaporative cooling. Navy dungarees are made from a mixed fabric, 35% cotton and 65% synthetic fiber, which does not seriously interfere with evaporative cooling. Physiological heat transfer comparisons have been made between Navy 100 percent cotton fire retardant coveralls (e.g., those used outside of engineering spaces) and mixed synthetic (5% Kevlar and 95% Nomex, known as "Aramid" and MIL-C–87093) fire retardant coveralls (e.g., engineering coveralls); no objective differences were found although personnel thought the mixed synthetic fiber coveralls were hotter. When the given mixed synthetic fiber coveralls were worn over underwear, like that with dungarees, there was no significant thermal difference between wearing the coveralls or dungarees. ***Physiological Heat Exposure Limit (PHEL) values do not need to be adjusted provided the coveralls are worn only over underwear.*** However, wearing either of the Navy coveralls over dungarees and underwear results in imposing a major heat load upon the body due to added insulation and weight; obviously

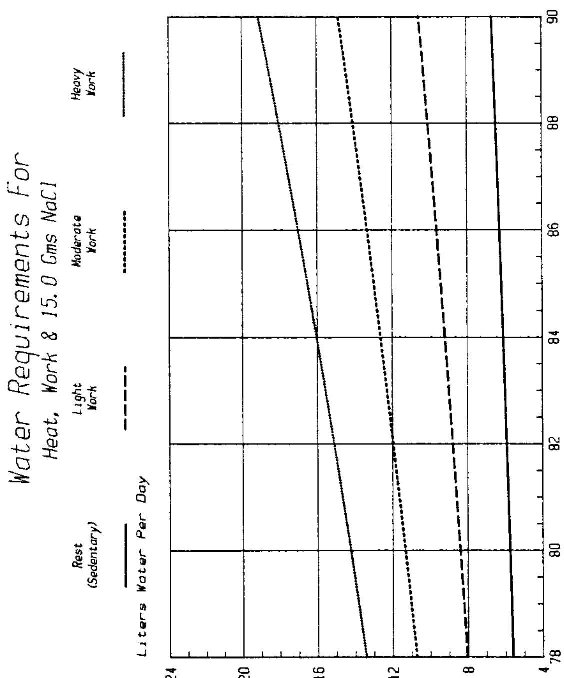


Figure 3-5.

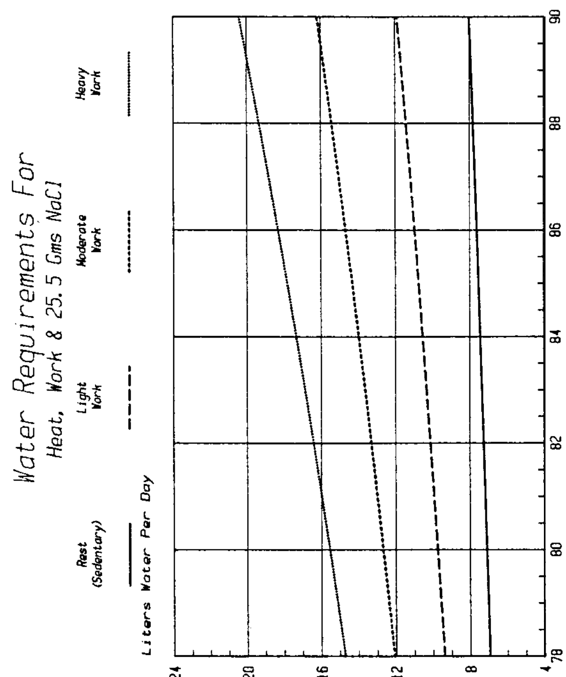


Figure 3-6.

this is a serious problem in the case of personnel being protected in damage control situations, but one must consider the added protection from fires. ***It is strongly recommended that coveralls not be worn over dungarees during damage or casualty control drills in hot and/or unventilated spaces, as this may readily induce heat exhaustion and heat stroke.*** Starch must not be utilized where evaporative cooling from clothing is a major factor. Outdoors, helmet liners or headgear of similar design provide more cooling and protection of the head than caps.

(5) ***Field Training Exercises.*** Training exercises requiring sustained or severe physical effort, and those conducted in the prone position should be scheduled, when possible, in early morning or at night. Outdoor classes should be conducted in the shade with adequate exposure to cooling wind. Even when training exercises are performed in early morning or at night, high metabolic heat production by those performing physical activity can induce heat exhaustion or heat stroke. One must, therefore, continue to be aware of all factors that may precipitate systemic heat injuries.

(6) ***Excessive Heat Stress.*** When environmental heat stress exceeds levels specified in Section IV, heat illness can be prevented by curtailing or suspending non-essential physical training and undue heat stress exposure. Obviously, operational mission requirements, excluding training programs, may preclude application of pertinent heat stress guides; in such cases the Medical Department must be forewarned in order to adequately prepare facilities and staff for the anticipated increased number of heat illnesses. Mental and physical dysfunction under thermal stress may be expected to amplify the frequency of accidental injury.

(7) ***Other Medical Measures.*** Other medical measures which will minimize the incidence of heat illnesses should be considered. Adequate recovery from acute or cumulative fatigue (at least 6 hours of uninterrupted sleep per 24 hours in a comfortable thermal environment), optimal physical fitness for the work to be done, absence of intercurrent illnesses, absence of febrile reactions (e. g., elevated body temperature due to immunizations), and absence of or minimal susceptibility to heat illnesses will aid in increased productivity of workers and help safe-guard their well being. Use of Navy educational films is strongly recommended (See Article 3-9(9) below).

(9) ***Educational Films.*** Navy educational films are available relative to the effects of heat stress, physical work, water requirements, sodium chloride intake and predisposing factors relative to heat disorders. The "all hands" film, "Heat Stress Monster" (35025-DN), is an animated film portrayal of multiple aspects of heat stress both ashore and afloat. On the other hand, "If You Can't Stand The Heat . . ." (35026-DN) is a counterpart film for supervisory level personnel afloat. Many of the informational aspects of this Chapter are presented in these films. Also see Article 3-2(2)(h) regarding the Navy educational film on "Care and Use of the Heat Stress Meter".

3-10. Effects of Cold

(1) The adverse effects of low environmental temperatures on the human body may be localized or generalized, or a combination of both. They may occur at temperatures above or below freezing and under wet or dry conditions. The pathophysiologic features of cold injury are dependent on the environmental temperature, exposure time and individual susceptibility or resistance. One form of adverse cold response has already been discussed under "cold shock" in Section 11, Article 3-6(4).

(2) ***General Physiologic Effects of Acute Cold Exposure.*** The physiologic response to total body cooling is manifested by the conservation of thermal energy and an increase in heat production. With prolonged or severe exposure, the defense mechanisms fail, heat loss exceeds heat production, and the body temperature falls. During the initial response to cold exposure, stimulation of the sympathetic nervous system causes a reflex superficial vasoconstriction with shunting of blood to the internal organs. This is accompanied by reflex shivering which increases muscular activity, heat production and oxygen consumption. Constriction of cutaneous capillary beds is manifested by pallor, mottling or cyanosis of the skin; in hypersensitive individuals histamine release may cause urticaria. In responding to stress the body secretes epinephrine which accelerates the cardiac rate, increases blood pressure and mobilizes liver glycogen stores. Blood coagulability is increased and pooling of water in the extravascular spaces (skin, muscle, subcutaneous tissues) results in hemoconcentration. Sudden exposure to extreme cold causes reflex muscle spasm and respiratory arrest. More gradual cooling eventually causes unconsciousness (88-89 F rectal) and is accompanied by slowing of respiration and heart rate, and falling of the blood pressure. Although some individuals have survived rectal temperatures as low as 72 F, ventricular arrhythmias (fibrillation) and cardiac arrest may be expected when rectal temperature falls below 80 F. In persons exposed to rain, snow, wind and cold, the onset of hypothermia may be insidious. The first warning may come with violent shivering, marked fatigue, stubbornest and hallucinations as the body temperature drops below 91-95 F. Unconsciousness and cardiorespiratory arrest may rapidly follow unless resuscitative efforts are begun immediately.

(3) ***Chronic Effects of Cold Exposure.*** It has been suggested that recurrent exposure to cold and to changes in environmental temperature may lower individual resistance to infectious disease. Research in this area is incomplete; therefore, definitive conclusions cannot be stated.

(4) ***Characteristics of Localized Cold Injury:***

(a) ***Nonfreezing Injury.*** Non-freezing injuries occur at ambient temperatures above 32 F, but below 50 F, and are most frequently manifested as chilblain (pernio) and cold water immersion foot (trench foot). Exposure time is variable but is usually measured in hours. A high environmental moisture favors non-freezing injuries by accelerating heat loss. Peripheral vasoconstriction, venostasis and increased blood viscosity impair normal tissue oxygenation and the removal of cellular metabolites. This may be accompanied by increased capillary permeability and intravascular agglutination or sludging of red blood cells. ***Chilblain is*** characterized by initial blanching and pallor—followed on rewarming by flushing, itching and edema. Blistering may be present and continued cold exposure may lead to hemorrhagic or ulcerative lesions. ***Cold water immersion foot*** may initially be no more troublesome than chilblain; however, prolonged exposure leads to more severe anoxic impairment. During the hyperemic phase the pain is usually severe, tissue destruction is more pronounced and gangrene may supervene with the resultant loss of the limb. Late complications of cold water immersion foot include dyshidrosis, Raynaud's phenomenon and causalgia. Secondary complications, including infection and thrombophlebitis, are not uncommon.

(b) ***Freezing Injury (Frostbite).*** The pathophysiology of frostbite is presently uncertain. It occurs only at environmental temperatures below freezing and the extent of tissue destruction depends primarily on the temperature and length of exposure. The freezing of intracellular and extracellular fluid results in the formation of ice crystals which mechanically disrupt cell membranes. There is a lack of agreement as to whether the injury is due to cellular injury and changes in vascular permeability or to the vascular stasis and tissue hypoxia. ***First degree frostbite*** is similar to mild chilblain with hyperemia, mild itching and edema; no blistering or peeling of the skin occurs. ***Second degree frostbite is*** characterized by blistering and desquamation. In ***third degree frostbite*** there is necrosis of the skin and subcutaneous tissues with ulceration. The most severe tissue damage is seen in ***fourth degree frostbite*** with destruction of connective tissues and bone accompanied by gangrene. Secondary infections and the sequelae noted for non-freezing injuries are not infrequent.

(5) ***Factors Influencing Cold Injury***

(a) ***Weather*** The prevention of cold injury is facilitated by the availability of accurate meteorological information, including air temperature, humidity and wind velocity. For practical purposes, the cooling effect of air temperature and wind velocity have been combined in the ***Equivalent Temperature*** standard (Wind ***Chill Index Chart)*** which is presented in Section IV.

(b) ***Physical Work.*** Heavy physical activity may accentuate heat loss by perspiration; in addition, the moisture becomes trapped in-excess clothing and reduces its insulating capacity. Prolonged excessive activity leads to mental and physical fatigue which may lead to fatal hypothermia in a cold environment. Total immobility, on the other hand, decreases the production of body heat with cooling of the extremities and circulatory impairment in dependent parts. It is advisable, therefore, to tread the middle ground and recommend moderate activity with adequate rest. Increased exercise of the extremities should be encouraged when personnel are in confined positions in cold climates.

(c) ***Physical Well-Being and General Health.*** Persons with previous cold injury, especially that of recent origin, heavy smokers and those taking medications which affect the vasomotor tone are at special risk in cold environments. Seriously wounded individuals with significant blood loss and decreased activity are predisposed to cold injury as are those on starvation or near-starvation diets. Consumption of alcoholic beverages causes vasodilation and accelerates heat loss, thus favoring the development of frostbite and hypothermia.

(d) ***Personal Characteristics.*** Although the epidemiologic reasons are unclear, younger lower ranking personnel, Caucasians from United States climates with minimum January temperatures above 20 F, and American Blacks appear to share an increased hazard of developing cold injury. Persons with negativistic behavior patterns are also at risk. Therefore, line commanders and Medical Department personnel may find it particularly valuable to concentrate preventive education among these individuals.

(e) ***Clothing.*** Protective clothing, available when needed and properly worn, is essential to conservation of body heat. Garments should be clean, dry and allow for adequate air circulation between and through layers. Apparel should be fitted so as to avoid peripheral limb constriction with attending circulatory impairment. The feet and hands require special care in order to avoid maceration of the skin and secondary infection. This is best accomplished by adequate changes of socks and gloves and liberal use of soap and water cleansing. When possible, footgear should be dried between periods of use.

(f) ***Preventive Education.*** All personnel should be oriented to their individual responsibility in the prevention of cold injuries. Predisposing and preventive factors should be widely promulgated, and negative attitudes discouraged.

(6) ***Treatment of Local Cold Injuries***

(a) ***First Aid.*** Frozen body parts should be rewarmed until thawed. This can be accomplished by immersion in a water bath of 104-106 F; temperatures above this level should be strictly avoided. In the field where water is not available, the part may be-warmed in the axilla of a normothermic companion. In most cases the frozen body part has already thawed by the time the victim comes for initial treatment and further active warming measures are not required. Wet clothing should be removed and body parts dried and protected from trauma. Blisters should be left intact and sterile fluff dressings applied. Deep body temperature should be maintained with blankets and warm liquids. All individuals with cold injury of the extremities should be managed as litter patients with the limb slightly elevated. All cold injury victims should be evaluated by qualified Medical Department personnel as soon as possible.

(b) AVOID: COLD-INJURED PARTS SHOULD NOT BE RUBBED WITH SNOW OR ICE WATER OR OTHERWISE TRAUMATIZED. BECAUSE OF THEIR EFFECTS ON CAPILLARY CIRCULATION, THE USE OF ALCOHOLIC BEVERAGES AND TOBACCO IS STRICTLY CONTRAINDICATED.

OINTMENTS AND CREAMS SHOULD NOT BE APPLIED.

(c) ***Symptomatic Care.*** Pain is sometimes severe in rewarmed limbs and may require administration of narcotics for relief. Itching and urtication may be relieved by antihistaminics and milder analgesics.

(d) ***Definitive Therapy:***

(1) Affected parts should be kept clean and either treated "closed" with sterile dressings or "open" with sterile sheets and proper nursing precautions.

(2) Tetanus boosters should be given where indicated.

(3) Since frostbite victims are frequently dehydrated, they may benefit from the administration of Lactated Ringer's Solution. Low-molecular-weight dextran or Heparin may be indicated if vascular "sludging" or thrombophlebitis are suspected.

(4) In frostbite devitalized and gangrenous tissues may separate spontaneously after 60-90 days. Sympathectomy may be indicated in severe cases of frostbite and immersion foot to relieve causalgic pain. Surgical debridement may become necessary as well as skin grafting. Amputation should be conservative.

(5) Physical therapy includes early active and passive movement of affected parts and later rehabilitation of compromised function.

(6) Antibiotic therapy may be necessary if secondary infection becomes a problem, and should ideally be guided by bacterial culture and sensitivity testing evidence.

(e) ***Disposition.*** All episodes of cold injury should be documented in the patient's medical records. Recurrent episodes may be cause for reassignment or medical board.

(7) ***Clinical Manifestations and Treatment of Generalized Hypothermia:***

(a) Generalized hypothermia may be classified as ***induced*** or ***accidental. Induced hypothermia is*** a valued adjunct to general anesthesia for select surgical procedures. It is implemented under controlled conditions by qualified personnel. Vital functions (circulatory, respiratory, cardiovascular) are carefully monitored as the body temperature is lowered and maintained for the duration of the surgery. Temperatures are generally maintained above 82 F. ***Accidental hypothermia*** may be observed in newborns, in the elderly and in association with certain lesions of the endocrine and central nervous systems. In the military, it is most frequently seen in individuals who have been exposed to cold for prolonged periods of time. Fatigue, severe wounds, cold water immersion (aircraft, ship and submarine accidents), and inadequate cold weather gear contribute to the evolution of accidental hypothermia. Case reports suggest that tolerance to deep hypothermia (77 F) may occasionally be enchanced by the depressant effect of alcoholic intoxication and excessive doses of sedative drugs. This phenomenon, however, is unpredictable and should never be considered in the context of therapy. Individual cold tolerance and the unreliability of the clinical signs of "death" during severe hypothermic episodes make it imperative that resuscitative measures be instituted immediately in all cases of accidental hypothermia. Cardiovascular and respiratory support should ideally be continued until it can be confirmed by more sophisticated means that all signs of life are absent.

(b) ***Clinical Manifestation of Hypothermia.*** The patient is pale, comatose, and may appear dead. Respirations are slow and shallow and may be difficult to detect. The pulse is faint or absent, the precordial impulse may be inapparent and the blood pressure is frequently unobtainable. The victim is hyporeflexic and unresponsive to painful stimuli. Pupils are unreactive to light, but are usually not dilated. The body tissues are semirigid and resist passive movement. Body temperatures are frequently below 82 F (rectally), and cannot be measured with the usual clinical thermometers (See below for Subnormal Clinical Thermometer). Urine output is negligible. Death may occur in spite of apparently successful resuscitative measures.

For clinical monitoring of hypothermic patients, there is a special thermometer available. The following information is provided:

> Thermometer, Clinical Human, Oral/Rectal, Subnormal(Range 70-100 F) Stock number 9L-6515-00-139-4593

(c) ***Therapy of Accidental Hypothermia:***

(1) ***Genera{ Measures.*** Initial resuscitative measures should concentrate on the restoration of vital functions. If respirations are present and ventilation is adequate, the therapists attention may be diverted to other resuscitative measures. Otherwise mouth-to-mouth resuscitation and external cardiac massage (if indicated) should be initiated in the field. The patient should be kept warm during transportation to a medical facility and examined for concurrent injury and drug or ethanol intoxication. Supplemental oxygen will usually be indicated. An oral airway should be inserted. Upon arrival at a medical facility, the apneic patient should have an endotracheal airway inserted to aid mechanical ventilation and suction. Intravenous lines should be established for the administration of resuscitative fluids and the measurement of central venous or pulmonary wedge pressures. A nasogastric tube will allow evacuation of stomach contents and prevent aspiration, and an indwelling urinary catheter will serve to monitor urine output. Blood gas, pH, and electrolyte determinations will aid in effective management. Body temperature is best monitored by rectal thermistor probe, otherwise use the subnormal clinical thermometer noted above.

(2) ***Rewarming.*** Rewarming must be approached with caution in order to avoid serious consequences. Controversy still exists as to the most effective and safest means by which to restore normal body temperature. ***Rapid rewarming*** appears to be the most effective in cases where cold exposure (most frequently cold water immersion) has been brief. It is accomplished by total body immersion in warm water (about 104 F). Hypothermic patients, however, may be inadvertently burned by this approach and are subject to the poorly understood phenomenon of "rewarming shock". Slow ***re-***

warming may be accomplished by the use of blankets, hot water bottles, etc.; however, care should again be taken that the differential temperature between the patient and the rewarming medium is not too great. ***The age old method of vigorously massaging the patient is dangerous and is contraindicated.***

(3) Cardiopulmonary Care. Vital signs should be closely monitored under intensive care nursing procedures. After restoration of respirations assisted ventilation and oxygen may be continued. Electrocardiographic monitoring is indicated. Ventricular arrhythmias (ventricular premature beats, tachycardia, and fibrillation) are not infrequent in severe hypothermia; intraventricular conduction delays are common and a “J-point” may be seen at the very end of each QRS complex. Digitalis may be indicated for rapid atrial fibrillation associated with a rapid ventricular response. Ventricular arrhythmias may be treated with lidocaine or procainamide; however, recent evidence suggests that quinidine and beta-adrenergic blocking agents (propranalol) may have a more predictable pharmacologic effect.

(4) ***Metabolic and Fluid Balance.*** Restoration of circulating fluid volume should be monitored by central venous or pulmonary wedge pressures. Blood gas and pH determinations are useful in following repair of the severe metabolic acidosis which accompany profound hypothermia. Ringer’s lactate is the restorative fluid of choice, and may be supplemented with sodium bicarbonate solution as indicated. Overzealous measures can lead to serious fluid overloading of the cardiopulmonary circulation. Marked hypoglycemia is best managed by the administration of glucose. Physical exhaustion and prolonged stress can lead to adrenal insufficiency; therefore, the administration of 200 mg of hydrocortisone intravenously may be indicated in some cases. Hypokalemia is common, but is probably due to intravascular electrolyte shifts and does not usually require vigorous replacement.

(5) ***Lute Measures and Complications.*** Associated injuries can be dealt with when rewarming is completed. Intensive care measures are needed only until the cardiopulmonary, metabolic, and thermoregulatory functions have stabilized. Patients must be watched for acute renal failure and pulmonary infection.

(8) ***Sensitivity to Cold.*** Sensitization to further cold exposure frequently follows all forms of cold injury. The sensitivity may be brief with milder injuries or last for years after severe episodes. Hypersensitivity to cold (cold allergy) may be observed as a familial trait or a sequela of cold injury. It is manifested by the appearance of generalized urticaria following cold exposure and may occasionally be complicated by bronchospasm (asthma) and shock.

warming may be accomplished by the use of blankets, hot water bottles, etc.; however, care should again be taken that the differential temperature between the patient and the rewarming medium is not too great. ***The age old method of vigorously massaging the patient is dangerous and is contraindicated.***

(3) Cardiopulmonary Care. Vital signs should be closely monitored under intensive care nursing procedures. After restoration of respirations assisted ventilation and oxygen may be continued. Electrocardiographic monitoring is indicated. Ventricular arrhythmias (ventricular premature beats, tachycardia, and fibrillation) are not infrequent in severe hypothermia; intraventricular conduction delays are common and a "J-point" may be seen at the very end of each QRS complex. Digitalis may be indicated for rapid atrial fibrillation associated with a rapid ventricular response. Ventricular arrhythmias may be treated with lidocaine or procainamide; however, recent evidence suggests that quinidine and beta-adrenergic blocking agents (propranalol) may have a more predictable pharmacologic effect.

(4) ***Metabolic and Fluid Balance.*** Restoration of circulating fluid volume should be monitored by central venous or pulmonary wedge pressures. Blood gas and pH determinations are useful in following repair of the severe metabolic acidosis which accompany profound hypothermia. Ringer's lactate is the restorative fluid of choice, and may be supplemented with sodium bicarbonate solution as indicated. Overzealous measures can lead to serious fluid overloading of the cardiopulmonary circulation. Marked hypoglycemia is best managed by the administration of glucose. Physical exhaustion and prolonged stress can lead to adrenal insufficiency; therefore, the administration of 200 mg of hydrocortisone intravenously may be indicated in some cases. Hypokalemia is common, but is probably due to intravascular electrolyte shifts and does not usually require vigorous replacement.

(5) ***Lute Measures and Complications.*** Associated injuries can be dealt with when rewarming is completed. Intensive care measures are needed only until the cardiopulmonary, metabolic, and thermoregulatory functions have stabilized. Patients must be watched for acute renal failure and pulmonary infection.

(8) ***Sensitivity to Cold.*** Sensitization to further cold exposure frequently follows all forms of cold injury. The sensitivity may be brief with milder injuries or last for years after severe episodes. Hypersensitivity to cold (cold allergy) may be observed as a familial trait or a sequela of cold injury. It is manifested by the appearance of generalized urticaria following cold exposure and may occasionally be complicated by bronchospasm (asthma) and shock.

Section IV. THERMAL STANDARDS

	Article
General Requirements	**3-11**
Assessment of Heat Stress	**3-12**
Practical Heat Stress Standards	**3-13**
Practical Cold Stress Standards	**3-14**

3-11. General Requirements

(1) The major objectives of the thermal standards are to facilitate mission accomplishment by maximizing productivity and maintaining the well-being of personnel.

(2) ***Elimination of Smoke and Noxious Odors.*** Smoke and noxious odors are readily detectable in closed spaces. Ventilation rates to eliminate odors from berthing areas and living quarters are considerably in excess of those required to supply oxygen and remove carbon dioxide. Attempts to filter or mask unpleasant odors have not met with significant success. Tobacco smoke is likewise difficult to remove from confined spaces aboard ship, particularly in submarines where air is recirculated. Noxious odors are not physically harmful, but tend to exert an unfavorable effect on appetite and morale. Tobacco smoke, on the other hand, may have varied harmful effects on smokers as well as non-smokers. Personnel exhibit a variable tolerance for tobacco smoke with some individuals developing symptoms of hypersensitivity (allergy). Smoke acts as an irritant to the eyes and respiratory membranes. Smoking should be prohibited in spaces where the carbon monoxide content of the air exceeds the following limits:

(a) 25 parts per million and continuous exposure for 90 days.

(b) 50 parts per million and exposure for 8 hours daily.

(Other standards exist depending on the length of exposure, physical activity performed and requirements for mental acuity.)

(3) ***Elimination of Fuel Combustion Gases and/or Fuel Vapors.*** Fuel combustion gases and fuel vapors have toxic effects upon personnel. In the area of thermal physiology, these gases and vapors cause vasodilation of the peripheral blood vessels at times when cardiovascular stability has already been compromised. Since humans cannot increase their existing circulating blood volume to compensate for the marked increase of their cardiovascular system capacity, the resultant effect is to incur further impairment of the cardiovascular system to meet the physiologic demands of the work and environment. This produces a critical impact when the added

load of heat stress is present. The ambient concentrations of aromatic hydrocarbons, using hexane as the reference gas for quantitative analysis, which produce such responses in humans is between 10-14 mg/m^3 of air. Higher concentrations of aromatic hydrocarbons have relatively little further effect on human short-term exposure; concentrations as high as 690 mg/m^3 have not resulted in significant changes from that measured at the lower concentrations. One must be aware that the threshold concentrations for aromatic hydrocarbons and oxides of nitrogen and sulfur, in combined environmental stress situations, appear to be quite low. Cardiovascular "shock" occurs without significant hyperthermic responses. Table 3-4 generalizes some of the physiologic impact of fuel combustion gases and fuel vapors where 135 personnel exhibited and sensed body changes due to the presence of these gases and vapors aboard Navy ships in mild heat stress situations. In all cases, the Physiological Heat Exposure Limits (PHEL) times alone were 4–6 hours, but the personnel exposures had to be terminated quite prematurely when the overall effects justified removal for physiological safety purposes.

Since the physiologic thresholds of the gases and vapors are low, the results from calorimetric detector tubes used aboard ships should be considered unreliable. Research has shown that ambient water vapor results in false low values from a variety of calorimetric detector tubes, water molecules occupy sites in the chemical beds and thereby reduce the number of available sites for reactions to occur in the detector tubes. Gas free engineering methods, generally available aboard ships, cannot reliably measure these low levels of likely toxic components in fuel combustion gases and fuel vapors that are pertinent to this subject. Portable, direct reading instrumentation which is durable, accurate at low concentrations, has specificity for a variety of atmospheric components, has a high degree of reproducibility, maintains calibration and has an adequate response time is extremely expensive. We are left with the difficulty of estimating the presence of physiologically significant levels of atmospheric contaminants and what to do to minimize the impact upon personnel, especially if the contaminants are permitted to remain in work spaces.

Table 3-4. General Physiologic Impact of Fuel Combustion Gases and Fuel Vapors

Parameters	Change
Cardiovascular:	
Heart Rate	Slight increase
Systolic Blood Pressure	Marked reduction
Diastolic Blood Pressure	Marked reduction
Mean Arterial Blood Pressure	Very marked reduction
Estimated Cardiac Output	Marked increase
Total Vascular Resistance	Very marked reduction
Overall Cardiovascular Reserve	Very marked reduction
Sensory:	
Tip of Tongue	Tingling/numbness
Nose	Tingling/numbness
Finger Tips	Tingling/numbness
Toes	Tingling/numbness
Eyes	Lacrimation
Respiratory	Distress
Body Temperatures	No apparent change at time of exiting environment

Fortunately, the Physiological Heat Exposure Limits (PHEL) Chart and information available regarding the sensory, eyes and respiratory responses of shipboard personnel in such environments exists. During what would normally be 4-6 hour heat stress exposure limits, it was repeatedly found that the physiologically safe exposure times could be determined by use of the PHEL Chart. Using the methods described in this Chapter and the OPNAVINST 5100.20 series for determining the WBGT Index and PHEL times, ***reduction of the determined PHEL exposure times by 66% would minimize the reduced physiologic performance of personnel.*** For example, a PHEL stay time of 4 hours becomes 1.4 hours (1 hr 24 reins) and 6 hours becomes 2.1 hours (2 hrs 6 reins). Therefore, adjustment of the PHEL values for heat stress exposures provides a simplified means of estimating physiological exposure times to fuel combustion gas and fuel vapor pressures, with and without the presence of limiting heat stress. Regardless, ***long-term, repetitive exposures to such atmospheric contaminants may have other far more serious consequences to the well-being of personnel.*** Obviously, the elimination of personnel exposures to fuel combustion gases and fuel vapors that adversely impact upon the health of personnel should be an engineering and operational goal. Personnel exposures to fuel combustion gases and fuel vapors must be prohibited on a routine basis, emergency exposure situations should be the only exception.

(4) ***Air Supply for Ventilation.*** One of the most important factors in the design of a ventilating system is the uniform distribution of air. Under favorable conditions the required air supply can be obtained by natural ventilation methods without creating objectionable drafts. The ***maximal*** air supply should be governed by thermal requirements for maintaining the desired working, living and messing space conditions indicated in Section II of this chapter. In cool or cold atmospheres, it is desirable to limit the velocity of air currents to within the threshold of perceptibility so far as to impart a sense of freshness without producing unpleasant drafts. The velocity at which room currents become noticeable varies with the dry- and wet-bulb temperatures, and ranges from a low of 10 fpm in cold environments to about 80 fpm or higher in warm environments. In order to avoid drafty conditions, air movement in cool atmospheres should be maintained at less than 50

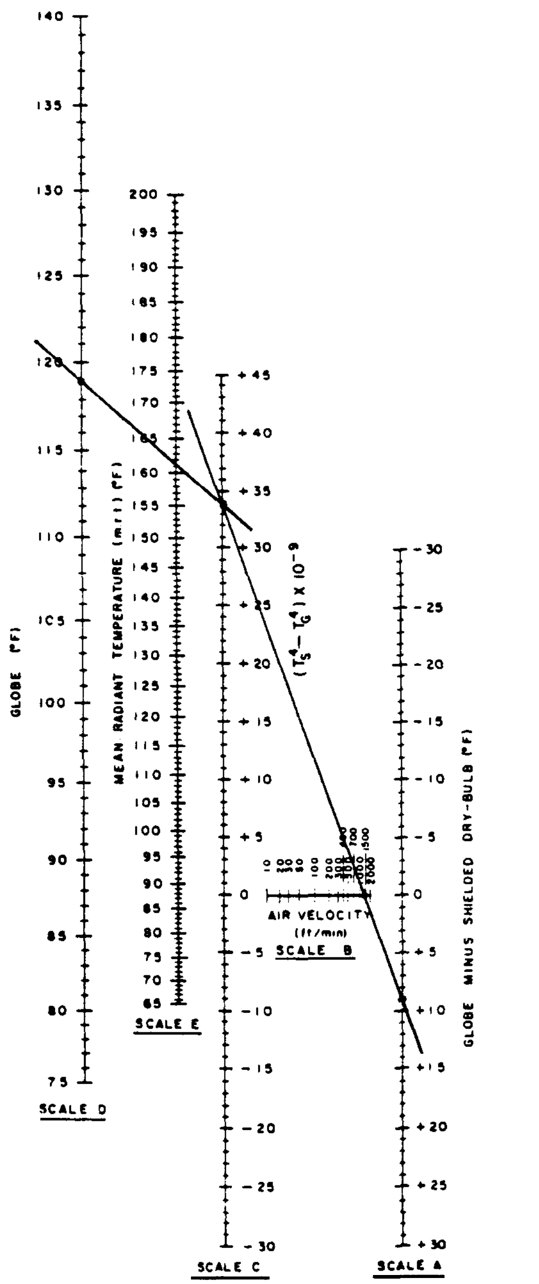
fpm; in warm conditions it should be kept between 100-200 fpm. Intermittent exposure to much higher velocities is indicated in the presence of radiant heat; however, reference should be made to the special considerations indicated in Section H, 3-7 (5) and (6). For natural ventilation it is good practice to select the point of air entry in order to control the volume and distribution. Selective entry of air through specific openings or by "infiltration" allows for thermal tempering before it reaches living or working spaces. When untempered air passes over personnel, it can result in chilling and complaints of drafts. Some individuals may then demand increased heating of a space to the dissatisfaction of other occupants. "Foot drafts" may be due to faulty ventilation or to variable vasomotor circulatory response in the extremities. It is best managed by selective use of suitable clothing. In firerooms and engine rooms the preferred minimal *effective air velocity* over personnel is 250 fpm. Air blowing between 250-1500 fpm on the head and shoulders will result in relatively little gains in effective cooling, beyond 1500 fpm there will be reduced effective cooling, while above 2080 fpm will result in heating of dry skin (See Figure 3-2).

(5) ***Air Supply Requirements for Respiration and Elimination of Smoke and Odors. Outside*** air supply to spaces where light work is performed should not be less than 425 liters (15 cubic feet) per minute per person; or 2 air changes per hour, whichever is greater. Where the work load is heavy, the outside air supply should be increased to 566 liters (20 cubic feet) per minute per man, or 3 air changes per hour. In spaces where smoking is permitted, 850 liters (30 cubic feet) of air should be provided per minute for each smoker. In living spaces 850 liters (30 cubic feet) of air should be supplied per minute per designed occupancy; messing areas should be provided with 566 (20 cubic feet) per minute per person eating during maximum occupancy. These are *minimal* air quantities for the removal of noxious odors and smoke and are not intended as standards for the removal of potential industrial contaminants.

3-12. Assessment of Heat Stress

(1) The empirical heat balance equation presented in Section 111 summarizes the environmental and metabolic parameters which constitute an individual's thermal load in a given environment. Efforts to develop an all-encompassing heat stress index, that unconditionally describes all thermal variables in all situations, have met with varying degrees of both success and failure. The usefulness of a single thermometer in the measurement of heat stress conditions is extremely limited. Engineering surveys of *heat stress* require separate readings (dry-bulb, wet-bulb, globe, and surface temperatures plus air velocities) at the supply duct face (opening) and at the work location. Environmental physiology studies of *heat stress* require the foregoing measurements in addition to the assessment of human body temperatures and individual work loads. The evacuation of *heat strain* requires all of the above measurements as well as a worker's heart rates, blood pressures and pre- and post-exposure body weights.

(2) ***Mean Radiant Temperature (mrt).*** In calculating the radiant heat balance between man and his environment, one must first estimate the mean radiant temperature of the surroundings. This may be calculated in various ways using the *globe and dry-bulb temperatures,* and the *air velocity* data noted above. The simplest method is by use of the nomogram illustrated in Figure 3-7. The difference between the globe and dry-bulb



ESTIMATION OF MEAN RADIANT TEMPERATURE (m.r.t)(°F)

Figure 3-7.

temperatures is entered on *Scale A;* a line is then drawn from this point through the point representing the appropriate air velocity on *Scale B,* and continuing until it intercepts *Scale C,* lastly, a line is drawn from the point representing the globe temperature on *Scale D,* so that it meets the intercept point on *Scale C* the mean radiant temperature is read from the point at which the second line crosses *Scale E.* To illustrate, let us suppose that the globe temperature = 119 F, the dry-bulb temperature = 110 F, and the air velocity = 1500 fpm; the mean radiant temperature is read from Scale E as being equal to approximately 161.5 F.

The more precise means of obtaining mean radiant temperature is by use of the following fourth power equation:

$$(T_S + 460)^4 \times 10^{-9} = (T_G + 460)^4 \times 10^{-9} + 0.1028\ V^{0.5}(T_G - T_{DB})$$

where

T_S = temperature of the surrounding environment (°F)
T_G = globe temperature (°F)
T_{DB} = dry-bulb temperature (°F)
V = air velocity (fpm)

The calculated mean radiant temperature is within approximately 1 F of that obtained by the simplified method using the nomogram.

Frequently persons overlook the importance of mean radiant temperature on workers. Figure 3–8 illustrates the mean radiant temperatures where low, moderate, high and excessive body heat storage occurs. Therefore, in our example given above, *the mean radiant temperature of 161.5 F is within the range of excessive body heat storage. This* emphasizes the need for radiant heat control in workplaces.

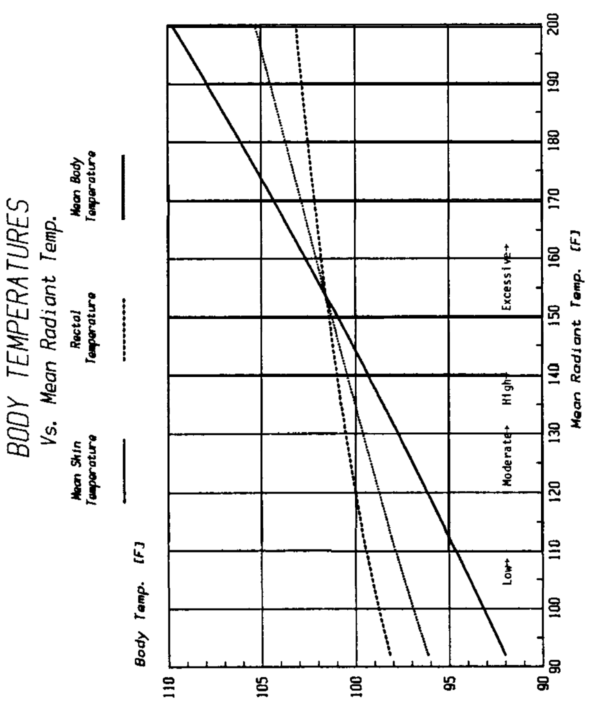


Figure 3–8.

(3) ***Radiation.*** The radiant heat transfer balance between a given subject and the environment may now be calculated using the following formula:

$$R = 6.27\ (\text{m.r.t.} - T_{sk}) \text{ assuming no clothing on the subject}$$

where

R = radiation (Kilocalories per hour)
m.r.t. = mean radiant temperature (°F)
T_{sk} = mean skin temperature (°F)

The value for R should be reduced by 30-40% for individuals insulated by clothing (the use of blue denim dungarees requires a 30% reduction factor).

(4) ***Convection.*** Heat exchange by convection is calculated by using the following formula:

$$C = 0.27\ V^{0.6}(T_{DB} - T_{sk}) \text{ assuming an unclothed subject}$$

where

C = convection (Kcal/hour)
T_{DB} = dry-bulb temperature (°F)
T_{sk} = mean skin temperature (°F)

The value for C should be reduced by 30-40% to account for the insulative effects of clothing (again 30% reduction for blue denim dungarees).

(5) ***Evaporation Estimates***

(a) ***Evaporation Required (Ereq):*** Evaporation required to maintain a normal heat balance within the human subject is calculated using the following equation:

$$E_{req} = M \pm R \pm C$$

where

E_{req} = evaporation required to maintain heat balance (Kcal/hr) assuming no heat storage if heat loss by E_{req} can be accepted by the environment
M = metabolic heat production by the subject (Kcal/hr)
R = radiation (Kcal/hr)
C = convection (Kcal/hr)

The equation assumes that conduction will be minimal if the subject is not in contact with a surface hotter or colder than his surface temperature and if heat transfer through the shoes is negligible.

(b) ***Maximum Evaporative Capacity (Emax):*** The maximum amount of heat, lost by evaporation, which can be accepted by the environment (maximum evaporative capacity of the environment) is calculated from the following equation:

$$E_{max} = 1.01\ V^{0.6}\,(42 - VP_a)$$

where

E_{max} maximum evaporative capacity (Kcal/hr)

v = air velocity (fpm)

VP_a = Partial vapor pressure of the environment (mm Hg.) at the combined dry-bulb and wet-bulb temperatures.

42 = vapor pressure at the skin of the subject assuming a mean skin temperature of 95° F; this figure will differ by approximately 1.3 mm Hg for each 1°F change in the mean skin temperature from 95ºF.

The value for Emax should be reduced by 30-40% to account for the insulative effect of clothing (blue denim dungarees require a 30% reduction factor).

(6) ***Heat Stress Index (Belding-Hatch):*** The Heat Stress Index (HSI) is calculated as the ratio of the Evaporation Required (Ereq) to the Maximum Evaporative Capacity (Emax):

$$HSI = \frac{E_{req}}{E_{max}} \times 100$$

The HSI is an expression of heat load in terms of the amount of sweat which needs to be evaporated in order to maintain heat balance. The index compares the amount of heat lost by evaporative cooling from completely wetted skin to the maximum evaporative capacity of the environment. The HSI was considered useful in subjectively estimating metabolic heat production during different categories of physical activity. Estimates of various types of metabolic rates during different physical activities are given in Table 3-5.

The Heat Stress Index was originally intended for application among men working 8-hour shifts in civilian industry. Investigation, however, has shown that a negative (–) index occurs when the vapor pressure of the skin is lower than the partial vapor pressure of the environment; this can happen even when the mean skin temperature is in the range of 101-110 F. Thus, *although a negative HSI theoretically indicates cold strain (See* Table 3-6) *it can,* in fact, *occur in the presence of severe heat strain.* The limitations of the HSI required development of a more reliable means of assessing *maximum safe exposure time* in the presence of heat stress. A more reliable exposure limit index has been developed and is discussed later in this section under the heading of *Physiological Heat Exposure Limits* (PHEL). Notwithstanding the contradictory nature of the HSI, the equations given in the preceding text are of use in partitioning the avenues of heat loss and gain between the subject and the environment.

(7) ***Wet-Bulb Globe Temperature Index (WBGT).*** As derived, the WBGT Index was unique in that it took into account the four physical variables of the thermal environment (air temperature, humidity, radiant heat and air movement). The simplicity of the approach was that one need not perform direct measurement of air velocity and that the globe thermometer integrates radiant heat and convective heating or cooling into one value. [Note: *The globe temperature is neither radiant heat by itself nor what is known as the mean radiant*

Table 3-5. Identification Of Approximate Metabolic Rates

Physical Activity	Average Metabolic Rate $KCal{*}m^{-2}{*}hr^{-1}$
a) ***Sitting***	
Moderate arm & trunk movement (e.g., typing, drafting, driving a car in light traffic)	68
Moderate arm & leg movement (e.g., general laboratory work, slow movement about an office)	82
Heavy arm & leg movement (e.g., driving a car in moderate traffic)	99
b) ***Standing***	
Light work at machine or bench, mostly arms	82
Light work at machine or bench, some moving about (e.g., using a table saw, driving a truck in light traffic)	99
Moderate work at machine or bench, some walking about (e.g., replacing tires, driving a car in heavy traffic)	119
c) ***Walking About, with Moderate Lifting or Pushing*** *(e.g.,* driving a truck in moderate traffic, scrubbing in a standing position)	164
d) ***Intermittent Heavy Lifting, Pushing or Pulling*** *(e.g.,* sawing wood by hand, calisthenic exercise, pick and shovel work)	238
e) ***Hardest Sustained Work***	300

temperature; the globe temperature value is a composite of radiant and convective heat transfers.]

Initial practical applications of the WBGT Index equations were to estimate ranges of heat stress that warranted decreasing physical activity in order to minimize incidence of heat injuries outdoors. It has been assumed by many persons over at least the last 20 years that the two-variable combination of wet and dry bulb temperatures applies *indoors,* while the three-variable equation applies only *outdoors.* In reality, *there are no less than eight equations for obtaining the WBGT Index;* therefore, *selection of the most appropriate WBGT Index equation became a serious matter in terms of the limitations of some of the equations.*

Table 3-6. Physiological Implications Of The HSI (Belding-Hatch)

HSI	Physiologic and Behavioral Implications
-20 to -10	Mild cold strain. (See implication of negative HSI above) This condition frequently exists in areas where men recover from exposure to heat.
0	No thermal strain.
+ 10 to +30	Mild to moderate heat strain. Where a job involve! higher intellectual function, dexterity, or alterness, subtle to substantial decrements in performance may be expected. In performance of heavy physics work, little decrement unless ability of individuals to perform such work under no thermal strain is marginal.
+40 to +60	Severe heat strain, involving a threat to health unless personnel are physically fit. Break-in period required for those not previously acclimatized. Some decrement in performance of physical work is to be expected. Medical selection of personnel desirable because these conditions are unsuitable for those with cardiovascular or respiratory impairment or with chronic dermatitis. These working conditions are also unsuitable for activities requiring sustained mental effort.
+70 to +90	Very severe heat strain. Only a small percentage of the population may be expected to qualify for this work. Personnel should be selected (a) by medical examination, and (b) by trial on the job (after acclimatization). Special measures are warranted to assure adequate water and salt intake (See Section III). Amelioration of working conditions by any feasible means is highly desirable, and may be expected to decrease the health hazard while increasing efficiency on the job. Slight "indisposition" which in most jobs would render workers unfit for this exposure.
+ 100	The maximum strain tolerated by fit, acclimatized young men for 8-hour exposures.
Above + 100	Overstrain, for 8-hour exposures. Tolerance of brief exposures will depend not on the amount by which the HSI exceeds + 100 but on the rate of heat accumulation by the body.

[Note: In steam, diesel and nuclear shipboard situations the level of heat stress frequently exceed physiological limits for at least 4-hour exposures. Therefore, one must consider a composite of heat stress and strain, behavioral, other physiological and time factors before application of the HSI to work situations less than the 8-hour design criteria.]

From 1963-1968, volumes of data were reviewed and compared with the Navy Bureau of Ship files. Literature searches and computer plotting of all available data indicated that maximum utility, for both engineering and environmental physiology purposes, would be obtained by use of the below WBGT equation. This was a major change from the comfort assessment concept of Effective Temperature and use of the WBGT Index.

WBGT = [(0.7 * Shielded Psychometric Wet Bulb)
+ (0.2 * Matte Black Globe Temp.)
+ (O. 1 * Shielded Dry Bulb Temp.)]

Extremely complex heat-work physiology experiments were conducted between 1968– 1975 in a large number of heat stress and work situations ashore and afloat. Seventeen physiological factors were employed, along with environmental variables and a wide range of work loads, to develop comprehensive physiological heat exposure limits criteria. Therefore, combining the given WBGT equation with the physiological responses led to development of the Physiological Heat Exposure Limits (PHEL). [Refer to: National Bureau of Standards, Special Pub. 491, pp 65-92, September 1977.]

Application of WBGT equations other than that given above for determining PHEL values is an extremely dangerous practice. There is too great a chance of being wrong in terms of physiologically safe but reversible limits of human heat stress exposures with other WBGT equations. Obviously one may find some theoretical situations where it makes no difference which equation is applied, however, for practical purposes, maximizing the utility of environmental data for many constructive and corrective engineering and environmental physiologic purposes, minimizing the risks to humans yet obtaining the longest safe stay times, there must be consistency in applying the above WBGT equation. The Navy heat stress meter is designed to be consistent with use of the given WBGT equation.

Only by use of above given WBGT equation, providing the raw data used for the calculations, including the air velocity over man, indicating what clothing is worn and providing sufficient information whereby human metabolic rates can be predicted will permit maximum analyses of the environmental physiologic situation. Whenever possible all available information should be provided ! Furthermore, extreme care should be taken to specify the presence or absence of air contaminants that may combine to have either a positive or negative impact upon humans at even low levels of heat stress. One must be continually aware of the fact that it is impossible for humans to be exposed to only one variable simultaneously in a non-laboratory environment. *It is essential to think in terms of dynamic situations where multiple environmental stresses result in various physiologic changes that occur in compensable or intolerable situations.* One must know as many possible individual variables to constructively analyze the work situation in terms of the physiological well-being of workers.

(8) ***Physiological Heat Exposure Limits (PHEL).*** U.S. Navy Physiologic Exposure Limits (PEL) were first established in 1971, however, in 1973 the Environmental Protection Agency circulated a series of Public Exposure Limits (PEL) covering a broad range of exposure limits which did not include heat stress. Furthermore, aware of the Navy's PEL for heat stress, the National Institute of Occupational Safety and Health (NIOSH) published their Permissible Exposure Limits (PEL) for heat stress in September 1973. In order to avoid confusion regarding the acronyms PEL the Navy, in December 1973, adopted the more descriptive title *"Physiological Heat Exposure Limits"* (PHEL). These criteria consisted of the previously published *Physiological Exposure Limits* of 1971 with an additional curve for heavy work as in casualty control. The Navy limits recognize that under conditions of maximum work and heat stress the heat strain will be readily apparent, but that it will be reversible; NIOSH Permissible Exposure Limits, on the other hand, were designed to restrict deep body temperature rises to a maximum of 100.4 F. In numerous work situations it is unrealistic to limit work at a rectal temperature of 100.4 F.

Compliance with the Navy's PHEL takes into account the multiple physiological factors relative to the welI-being of personnel. The PHEL applies to greater than 95070 of the population, as there will always be someone who may occasionally exceed the limits before incurring heat exhaustion or heat stroke. For the purpose of comparison, exceeding the PHEL is the same as stretching a rubber band close to its break point; sooner or later the rubber band is going to break. Serious personnel heat injuries can be expected whenever the PHEL are exceeded, therefore, stretching the rubber band close to its limits too many times is courting disaster.

(a) ***Criteria for PHEL Chart Development.*** The development of the PHEL curves entailed considerable heat stress research among personnel whose ages ranged from 18-40 years. Physiologic measurements included nine cardiovascular and four respiratory functions and related them to the total cardiovascular reserves. Three internal body temperatures and 10 skin temperatures were serially recorded. The criteria for determining maximum safe physiological exposures was based upon a composite of the above parameters (Refer to National Bureau of Standards, Special Publication 491, pp 65-92, September 1977). The absence of muscle damage under variable conditions of heat stress was verified by enzyme assay. In addition, subjects were monitored for the occurrence of hyperventilation and changes in mental status, particularly for euphoria. The measurements were made before, during and following sustained physical work in controlled heat stress conditions. These findings were compared with a wide range of environmental conditions aboard ships from 197 1-1976; the field data, using over 200 healthy Navy personnel, compared equally with the involved laboratory studies.

Time-weighted-means were calculated for both metabolic heat production and WBGT exposures. This allowed for the subsequent development of maximum heat exposure limits which were described by a family of six curves that fit power regression equations. Figure 3-9 illustrates the six major PHEL curves.

(b) ***Time Weighted Mean Metabolic Rates (twin).*** The "time-weighted-mean" (Twin) concept must be applied in unique situations not addressed as part of Physiological Heat Exposure Limits (PHEL) for shipboard applications. PHEL Curve Selection Tables for shipboard applications have taken into account the various work rates of personnel during various types of and lengths of time each activity is performed (normal watch, casualty control exercise and repair involving heavy work), therefore, do not apply the Twm concept to those situations. In cases where new or additional Twm situations occur it is essential to determine both the Twm Metabolic Rate, and may be necessary to determine the

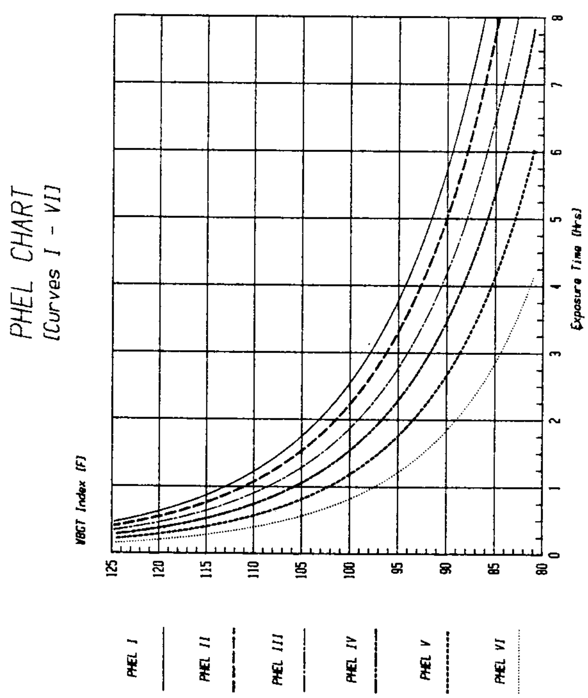


Figure 3-9.

Twm WBGT value and calculate the Twm PHEL Specific value.

(c) Procedure for Time-Weighted-Mean Applications:

1. Identify the metabolic rates (MR) for each segment of the total time under consideration, using Table 3-5.
2. ***Calculation of Twm Metabolic Rate***

Twm MR = [(MR1 * tl) + (MR2 * t2) + . . . + (MRn * tn)] / [tl + t2 + . . . + tn)]

where;

Twm MR = time-weighted-mean metabolic rate (KCal*m^{-2}*hr^{-1})
MR1 = metabolic rate (Kcal*m^{-2}*hr^{-1}) work for exposure time #1
tl = length of time (in decimal hours) for MR1
MR2 = metabolic rate (Kcal*m^{-2}*hr^{-1}) work for exposure time #2
t2 = length of time (in decimal hours) for MR2
MRn = metabolic rate (Kcal*m^{-2}*hr^{-1}) work for exposure time #n
tn = length of time (in decimal hours) for MRn

3. ***Relationship of Twm Metabolic Rates to PHEL Curves***
4. ***Identification Of Appropriate WBGT Curves***
If the Twm MR from #2 above is close to a Twm MR in #3 above, then proceed with Table 3-8 below in selecting the appropriate PHEL Curve:
5. ***Determination of Twm WBGT***
Determine WBGT values for each of the locations were the Twm Metabolic Rates apply. Then apply the WBGT values and times for the respective Twm Metabolic Rates to the equation given in Step #6 below.
6. ***Calculation of Twm WBGT Values***

Twm WBGT = [(WBGT1 * tl) + (WBGT2 * t2) + . . . + (WBGTn * tn)] / [tl + t2 + . . . +tn)]

where;

Twm WBGT = time-weighted-mean WBGT Index degrees F
WBGT1 = WBGT at time #1
tl = length of time (in decimal hours) for WBGT1
WBGT2 = WBGT at time #2
t2 = length of time (in decimal hours) for WBGT2

Table 3-7

PHEL Curve	Twm Metabolic Rate
I	76
II	86
111	96
Iv	106
v	116
VI	126

Table 3-8

Type of Physical Activity	PHEL Curve Selection Tables For No. Minutes Work vs. No. Minutes Rest				
	50/10	40/20	30/30	20/40	10/50
Sitting					
Moderate arm & trunk movement	I	I	I	I	I
Moderate arm & leg movement	I	I	I	I	I
Heavy arm & leg movement	III	II	I	I	I
Standing					
Light work at machine or bench, mostly arms	I	I	I	I	I
Light work at machine or bench, some walking about	III	II	I	I	I
Moderate work at machine or bench, some walking about	VI	III	II	I	I
Walking About, with Moderate Lifting or Pushing	(NA)	VI	IV	III	I
Intermittent Heavy Lifting, Pushing or Pulling	(NA)	(NA)	(NA)	V	II
Hardest Sustained Work					
Lowest Metabolic Rate	(NA)	(NA)	(NA)	VI	III
Average & High Metabolic Rate	(NA)	(NA)	(NA)	(NA)	III

NOTES:
1. Do Not Attempt To Apply The PHEL Curves and/or Work Rates In Those Situations Indicated As "NA" (Not Applicable) Above. If the amount of work is underestimated it is likely that personnel systemic heat injuries will be incurred.
2. If the types of physical activity are more mixed than noted above, then there is no alternative but to resort to calculations using the TWM concept.
3. TWM metabolic rate calculations require restarting with Step #l above and selecting the metabolic activity for the specific type of work given above, as well as the length of time that applies to the selected metabolic rate situation. Then apply the selected metabolic rate and time values to the below calculations. Do likewise for the WBGT and respective time values.

WBGTn = WBGT for exposure time #n

tn = length of time (in decimal hours) for WBGTn

7. ***Calculation of Twm Approximated PHEL Values***
Twm Approximated PHEL = Antilog [(1/0. 13) * (A-Log Twm WBGT)] = hours

A = Log [111.0461 + (0.2377 * Twm MR) – (0.0027 * Twm MR^2)] WBGT = degrees F

PHEL values greater than 8 hours should be read as " >8 hours" for the upper limits.

8. ***Reduction of PHEL Times Due to Fuel Combustion Gases and/or Pre-Combustion Fuel Vapors***
PHEL times (hours) must be reduced by 65.6070 when there is the presence of fuel combustion gases and/or pre-combustion fuel vapors.

(d) ***Relationships of PHEL Curves to Rest/Work Ratios.*** The laboratory data which led to the generation of the PHEL curves allowed for the development of a related series of rest/work ratios for different degrees of physical activity. These relationships are illustrated in Table 3-8 above.

(e) ***Precautions.*** It must be emphasized that the Physiological Heat Exposure Limits are ***maximum*** allowable standards and that they should be applied only in cases of short-term work exposures of up to 8 hours duration. The limits presume that no prior heat injury is present and that no cumulative heat fatigue exists prior to re-exposure.

(9) ***Other Indices.*** Other indices of heat stress and strain are available but are of limited use. The value of any index is dependent upon the nature and extent of the problem, the availability of resources, and the experience of local personnel in regard to heat stress analyses. Consultation will be provided to commands if inquiries are directed to the Naval Medical Command through official channels.

(10) ***Information Regarding the "Wet Globe Temperature" (WGT) Index.*** The WGT Index ("Botsball") has been used in a number of situations, however, it is not appropriate to utilize the WGT to determine Physiological Heat Exposure Limits. Army meteorological studies have shown that in identically the same environmental conditions no two WGT thermometers indicated the same value, there was a marked bleaching of the black cloth coverings after one month in use, the cloth coverings had various degrees of bristle formations, the coverings occasionally did not wet uniformly, the water reservoirs frequently need refilling at one hour intervals, WGT units required at least 5 minutes of stabilization after replenishing water in the reservoir, and the WGT values do not permit availability of essential data (dry- and wet-bulb and globe temperatures) for thermal analyses. Since 1971 there have been 8 equations published that claim to permit conversion of WGT values to WBGT values, there is a tremendous disparity between the products from these equations. Application of available data, with and without conversion to estimated WBGT values, to the PHEL chart has yielded unrealistic safe exposure times. There have been similar unacceptable findings regarding the use of WGT values for estimating the amount of water needed when personnel perform work. Use of the WGT units may be expedient but application of the WGT values has extremely limited value. NAVMEDCOM has not approved the use of the WGT ("Botsball") units.

(11) ***Predicting Onset Of Mental Impairment Due To Heat Stress.*** In 1972 the Department of Health, Education and Welfare (HSM 72-10269, 1972, pg 188) published a curve entitled "Upper Limits of Exposure for Unimpaired Mental Performance". Figure 3-10 illustrates the curves for detectable onset of mental impairment as a function of the same metabolic rates for the PHEL curves; the decrements of cardiovascular reserve also have been taken into account. It is readily apparent, by comparing Figure 3-9 (in Article 3-12) with Figure 3-10, that mental impairment begins much earlier and at lower heat stress conditions than persons reaching their physiological exposure limits. In heat stress conditions it can be expected that mental acuity will have been impaired long before workers reach their physiological limits, physical performance decays in a similar fashion as that shown for mental impairment but in a different time frame.

3-13. Practical Heat Stress Standards

(1) ***General.*** Sound health, physical conditioning for the specific task, and adequate rest and nutrition are essential in minimizing the effects of thermal stress. Drinking water should be unrestricted and readily available. Threshold WBGT values for the hottest 2-hour

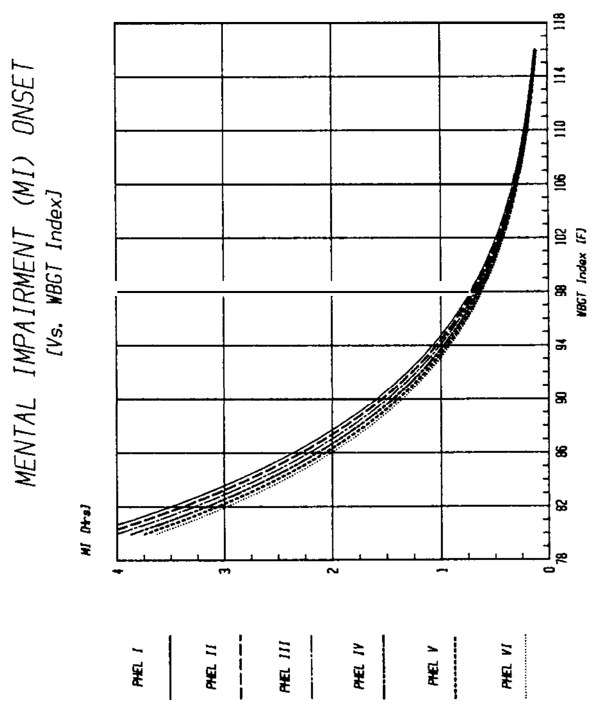


Figure 3-10.

period of *industrial-type work shifts* should be determined using the work load of personnel as described in Section 3-8 and Table 3-5. The threshold WBGT values versus work levels are repeated below:

Work Level	WBGT (F)
Light	86
Moderate	82
Heavy	

(2) ***Limitations on Physical Exertion.*** During the first 12 weeks of hot weather training the limits of physical exertion should be determined by the degree of environmental heat stress, metabolic heat production, the status of acclimatization, and the physical status of individual personnel. The availability of adequate drinking water and the frequency of rest periods should also receive consideration. Individuals who are over 35 years of age, those who are obese or whose nutritional status is poor, and those with evidence of chronic or acute cardiopulmonary dysfunction should be medically screen *prior to* physical exertion under thermal stress. Table 3-9 outlines the recommendations for different physical activities at five WBGT Index ranges. It applies especially to personnel during training and recreational exercises in hot weather. *The below table is not a substitute for the PHEL curves nor is it possible to comply with the table in combat situations.*

(3) Heating Standards.

(a) ***Surface Vessels.*** The recommended standards for heating *aboard surface vessels* imply an optimum dry-bulb temperature of 70 F for the following spaces:

(1) Living compartments, recreation and messing spaces.

(2) Medical and dental spaces.

(3) Office and control spaces.

Humidity control is not usually provided. Special requirements should be reviewed by the Medical Department before any action is taken.

(b) ***Submarines.*** Aboard submarines environmental conditions are more closely controlled. Heating standards should fall within the optimal limits of 79 F DB, 59 F WB, 50% RI-I with 63 F WBGT. These standards apply to:

(1) Living compartments, recreation and messing spaces.

(2) Medical and dental spaces.

(3) Office and control spaces.

(c) ***Other Compartments.*** Excluding the above noted spaces and those associated with engineering propulsion components, inside working spaces are usually maintained at lower temperatures during the winter. In these spaces, the control of personal warmth is facilitated by the proper use of available clothing.

(4) ***Ventilation and Air-Conditioning***

(a) ***Surface Vessels.*** Ventilation and air-conditioning standards for surface vessels should include the following upper limits for physical comfort and functional well-being: 80 F DB, 68 F WB, 55070 RH (14.3 Torr VP), with 72 F WBGT Index. The recommendations appIy to the same spaces noted for the heating standards above. In addition, air-conditioning and ventilation are required for manned electronics spaces and compartments with equipment sensitive to changes in temperature and humidity.

(b) ***Submarines.*** The standards for comparable spaces aboard submarines are as follows: 80 F DB, 67 F WB, 50% RH, with 71 F WBGT.

(c) ***Other Compartments.*** Laundries, galleys, sculleries, passages not opening directly on weather decks, and areas above food serving lines present situations in which it is difficult to contain heat and humidity within specific narrow limits. Standards for these areas, however, should allow for physical health and well-being; the WBGT Index should not exceed 78 F during normal operations. In addition, ventilation and cooling of such spaces should be consistent with the information given in Articles 3-6 and 3-7 (Section H) and Article 3-11 (Section IV) of this chapter. Design criteria presented in Table 3-1 (Article 3-7, Section 11) must be considered in planning ventilation for firerooms, engine rooms, laundries, sculleries, galleys and steam catapult launch con-

Table 3-9. WBGT as a Guide in Regulating Intensity of Physical Exertion During First 12 Training Weeks in Hot Weather*

WBGT Index [F]	Flag color	Intensity of Physical Exercise
Less Than 82	Blue	Extremely intense physical exertion may precipitate heat exhaustion or heat stroke, therefore, caution should be taken.
82-84.9	Green	Discretion required in planning heavy exercise for unseasoned personnel. This is a marginal heat stress limit for all personnel.
85-87.9	Amber	Strenuous exercise and activity (e.g., close order drill) should be curtailed for new and unseasoned personnel during the first 3 weeks of heat exposure.
88-88.9	Red	Strenuous exercise curtailed *for all personnel with less than 12 weeks training* in hot weather.
90 and Above	Black	Physical training and strenuous exercise suspended *for all personnel* (excludes operational commitment not for training purposes).

* *This table must not be used in lieu of the Physiological Heat Exposure Limits (PHEL).* The time-weighted-mean metabolic rates applicable to Table 3-8 are considerably higher than those for PHEL Curves. For an analogy, Table 3-8 would apply to Marine Corps personnel in the field, whereas the PHEL concept applies to industrial settings.

trol rooms. In situations where the heat stress is excessive and ventilation or cooling cannot be improved, the Physiological Heat Exposure Limits need to be employed to minimize the incidence of personnel heat injuries.

(5) ***Shipboard Heat Stress Situations***

(a) ***Physiological Heat Exposure Limits (PHEL) Chart.*** The PHEL chart illustrated in Figure 3-9 (Article 3-12) provides the relationships of various metabolic rates, heat stress and maximum safe exposure times. Applicability of PHEL curves to routine watches and casualty control exercises are given in Table 3-10 below, and the PHEL times for Figure 3-9 and Table 3-10 PHEL curves are given in Table 3-11; where there is no apparent presence of fuel combustion gases (or "stack gas") and/or fuel vapors. In all given situations the Twm metabolic rates have been utilized, whereby the varied activities (including movements about the spaces) and lengths of time for the various activities have been taken into account. For *Remaining Safe Stay Time* situations, where different heat stress conditions, actual exposure times and/or recovery times apply, see *Section (5)(b) below.* When it is apparent that fuel combustion gases (or "stack gas") and/or fuel vapors are present, use PHEL times given in Table 3-12.

Table 3-10. Physiological Heat Exposure Limit Curve General Applicability

Personnel	Routine Watch	* Casualty Control Exercise
Section 1. *Steam Propelled Ships*		
A. Fire Room:		
1. Boiler Tech. of the Watch (BTOW)	II	II
2. ABC Console Operator	I	I
3. Upper Levelman	II	III
4. Lower Levelman	III	IV
5. Burnerman	II	III
6. Messenger	III	IV
B. Engine Room: [Including Nuclear]		
I. Engineering Officer of the Watch [EOOW]	I	I
2. Machinist Mate of the Watch [MMOW]	II	III
3. Throttleman	I	I
4. Electrician Mate of the Watch [EMOWJ	I	I
5. Upper Levelman	II	III
6. Lower Levelman	II	III
7. Evaporator Watch	I	Not Applicable
8. Messenger	III	IV
C. Auxiliary Spaces [CV'S and FF 1052's]:		
1. Upper Levelman	II	II
2. Lower Levelman	II	II
D. Steam Catapult Launch Control Room:		
1. All Watch Personnel	II	II
Section 11. *Diesel Propelled Ships*		
A. Engineering Officer of the Watch [EOOW]	I	I
B. Petty Officer of the Watch [POOW]	II	III
C. Electrician Mate of the Watch [EMOW]	I	I
D. Throttleman	I	I
E. Repair Electrician	I	I
F. Ship's Service Diesel Generator Watch	I	I
G. Boiler Watch	I	I
H. Evaporator Watch	II	I
1. Oiler/Messenger	III	IV
Section III. Gas *Turbine Propelled Ships*		
A. All Engineering Watch Personnel	I	II
Section IV. *All Ships and Submarines*		
A. Engineering Casualty Control Evaluation Team [ECCET]	Not Applicable	II
B. Roving Watch Personnel	III	III
C. Laundry Personnel	III	Not Applicable
D. Scullery Personnel	**V**	Not Applicable
E. Galley and Food Serving Line Personnel	II	Not Applicable
F. Fleet Training Group Instructors and Other Off-Ship Engineering Observers	I	II
G. Personnel Conducting Heavy Repairs or Other Strenuous Work	VI	VI

* The work rate during Casualty Control Exercise is much less than that needed for repair involving heavy work. Different PHEL Curve selections are required for different work rates during the Exercise Phase, however, *all heavy work situations require use of PHEL Curve VI.*

(b) ***Remaining Safe Stay Times.*** There are a number of situations where it is necessary to estimate the remaining safe stay times relative to various heat stress conditions, different work levels and/or to account for recovery periods. Generally this is a complex task, however, a simplified approach is given in the below equation:

$$RSSt = [(1 - (Et - R/2)) / Atl] * At2$$

where:

Table 3-11. PHEL Time Limits for PHEL Curves I - VI Without the Presence of Fuel Combustion Gases and/or Fuel Vapors [WBGT 80.0 -125.0 F]

WBGT Index (F)	**Six** PHEL Curves (Total Exposure Times In Hours: Minutes)					
	I	II	III	IV	V	VI
80.0	>8:00	>8:00	>8:00	8:00	*6:35*	*4:30*
81.0	>8:00	>8:00	>8:00	7:45	*6:00*	*4:05*
82.0	>8:00	>8:00	*8:00*	7:05	*5:25*	*3:40*
83.0	>8:00	>8:00	*7:45*	6:25	*4:55*	*3:20*
84.0	>8:00	8:00	*7:05*	5:55	*4:30*	*3:05*
85.0	6:00	6:00	*6:00*	5:20	*4:05*	*2:50*
86.0	6:00	6:00	*5:55*	4:55	*3:45*	*2:35*
87.0	6:00	6:00	*5:25*	4:30	*3:25*	*2:20*
88.0	6:00	5:55	*4:55*	4:05	*3:10*	*2:10*
89.0	6:00	5:25	*4:30*	3:45	*2:50*	*2:00*
90.0	5:40	5:00	*4:10*	3:25	*2:40*	*1:50*
91.0	5:15	4:35	*3:50*	3:10	*2:25*	*1:40*
92.0	4:50	4:10	*3:30*	2:55	*2:15*	1:30
93.0	4:25	3:50	*3:15*	2:40	*2:00*	1:25
94.0	4:05	3:35	*3:00*	2:25	*1:50*	1:15
95.0	3:45	3:15	*2:45*	2:15	*1:45*	1:10
96.0	3:25	3:00	*2:30*	2:05	*1:35*	1:05
97.0	3:10	2:45	*2:20*	1:55	*1:25*	1:00
98.0	2:55	2:35	*2:10*	1:45	*1:20*	0:55
99.0	2:40	2:20	*2:00*	1:40	*1:15*	0:50
100.0	2:30	2:10	*1:50*	1:30	*1:10*	0:45
101.0	2:20	2:00	*1:40*	1:25	1:05	0:45
102.0	2:10	1:50	*1:35*	1:15	1:00	0:40
103.0	2:00	1:45	*1:25*	1:10	0:55	0:35
104.0	1:50	1:35	*1:20*	1:05	0:50	0:35
105.0	1:40	1:30	*1:15*	1:00	0:45	0:30
106.0	1:35	1:25	1:10	0:55	0:45	0:30
107.0	1:30	1:15	1:05	0:50	0:40	0:25
108.0	1:20	1:10	1:00	0:50	0:35	0:25
109.0	1:15	1:05	0:55	0:45	0:35	0:25
110.0	1:10	1:00	0:50	0:40	0:30	0:20
111.0	1:05	1:00	0:50	0:40	0:30	0:20
112.0	1:00	0:55	0:45	0:35	0:25	0:20
113.0	0:55	0:55	0:40	0:35	0:25	0:15
114.0	0:55	0:45	0:40	0:30	0:25	0:15
115.0	0:50	0:45	0:35	0:30	0:20	0:15
116.0	0:45	0:40	0:35	0:25	0:20	0:15
117.0	0:45	0:40	0:30	0:25	0:20	0:10
118.0	0:40	0:35	0:30	0:25	0:15	0:10
119.0	0:35	0:35	0:25	0:20	0:15	0:10
120.0	0:35	0:30	0:25	0:20	0:15	0:10
121.0	0:35	0:30	0:25	0:20	0:15	0:10
122.0	0:30	0:25	0:20	0:15	0:15	0:10
123.0	0:30	0:25	0:20	0:15	0:10	0:10
124.0	0:25	0:25	0:20	0:15	0:10	0:05
125.0	0:25	0:20	0:20	0:15	0:10	0:05

RSST = remaining safe stay time (in minutes)
Et = elapsed time on station (in minutes)
R = recovery time in a cool environment (in minutes)
Atl = allowed PHEL time in first environment (in minutes)
At2 = allowed PHEL time in second environment (in minutes)

Four examples will help illustrate the importance of calculating Remaining Safe Stay Times:

1. The level of physical work was changed from heavy to light work and the heat stress is higher in the light work phase, the elapse time of the first exposure is known, and no recovery is permitted between the two levels of physical work.
   a. Elapsed exposure time in the first heat stress condition was 3 hours (180 minutes).
   b. The first heat stress condition had a WBGT of 83.0 F and work was consistent with PHEL Curve VI. [PHEL VI at 83.0 F permits a maximum of 3 hours 20 minutes (200 minutes)]
   c. There was no recovery in a cool environment between the first environment and the second (WBGT 94.3 with work equal to PHEL Curve I). [PHEL I at 94.3 F permits a maximum of 4 hours (240 minutes).]

   Therefore, RSSt#l = [(1 – (180 – (0/2))/ 200] * 240 = 24 minutes. The second exposure situation should not exceed 24 minutes.
2. The level of physical work was unchanged at the same heat stress level but the two exposures were separated by a 40 minute recovery period in a cool environment; the elapsed time was known for the first exposure.
   a. Elapsed exposure time in the first heat stress condition was 3 hours (180 minutes).
   b. Both heat stress conditions had WBGT values of 91.3 F and the level of work was consistent to PHEL Curve I in both cases. [PHEL I at 91.3 F permits a maximum of 5 hours 8 minutes (308 minutes) each]
   c. Recovery, between the two exposures, was permitted for 40 minutes.

   Therefore, RSSt#2 = [(1 - (180 - (40/2))/ 308] * 308 = 148 minutes or 2 hours 28 minutes. The second exposure situation should not exceed 2 hours 28 minutes.
3. The level of physical work was the same in two different heat stress environments, the exposure time in the first condition was known, and the two exposures were separated by a 40 minute recovery in a cool environment.
   a. Elapsed exposure time in the first heat stress condition was 3 hours (180 minutes).
   b. The first heat stress condition had a WBGT of 91.3 F and work equalled that for PHEL Curve I. [PHEL I at 91.3 F permits a maximum of 5 hours 8 minutes (308 minutes)]
   c. There was 40 minutes recovery in a cool envi-

ronment between the first environmental exposure, and the second exposure at a WBGT of 94.3 F with work equivalent to PHEL Curve I. [PHEL Curve I at WBGT of 94.3 F permits 4 hours (240 minutes) stay time]

Therefore, RSSt#3 = [(1 – (180 – (40/2))/ 308] * 240 = 115 minutes or 1 hour 55 minutes. The second exposure situation should not exceed 1 hour 55 minutes.

4. The level of physical work changed from an intermediate level to lighter level and the heat stress was considerably higher in during the second exposure. Both the elapsed time for the first exposure and the recovery time between exposures were known.
   a. Elapsed exposure time in the first heat stress condition was 3 hours 15 minutes (195 minutes)
   b. The first heat stress condition had a WBGT of 87.7 F and work was consistent with PHEL Curve IV. [PHEL IV at 87.7 F permits a maximum of 4 hours 15 minutes (255 minutes)]
   c. There was 50 minutes recovery in a cool environment between the first exposure and the second, the work during the second exposure was equivalent to PHEL Curve II, but the WBGT value was 100.9 F for the second exposure. [PHEL 11 at 100.9 F allows a maximum of 2 hours 5 minutes (125 minutes)]

   Therefore, RSSt#4 = [(1 – (195 – (50/2))/ 255] * 125 = 42 minutes. The second exposure situation should not exceed 42 minutes.

NOTE: *In application of the Remaining Safe Stay Time equation it must be acknowledged that some cumulative fatigue will take place.*

(c) Presence of Fuel Combustion Gases and/or Fuel Vapors. As indicated in Article 3-11(3), the apparent presence of fuel combustion gases (or "stack gas") and/or fuel vapors has a deleterious impact upon workers. To minimize excessive exposures it is possible to utilize the PHEL Curves provided the stay times are reduced 66%. *Table 3-12 provides the reduced PHEL values* compared with those given in Table 3-11.

(d) ***Alternative Options for Regulating Heat Stress.*** It is sometimes impossible to control environmental heat within the specified limits in the face of increased operational demands. Alternative measures may therefore be useful in limiting heat stress and reducing the incidence of heat casualties. Several options are possible:

(1) Insulate the source of heat.

(2) Ventilation with cool air (Section II of this chapter).

(3) Reduce humidity (partial water vapor content) by stopping steam leaks and venting steam to the outside.

(4) Provide clothing which will maximize evaporative cooling.

(5) Limit exposure time (refer to PHEL Chart).

(6) Avoid cumulative fatigue; maintain overall physical health.

(7) Eliminate the presence of fuel combustion gases and fuel vapors.

(8) Automate and isolate operations which generate excessive heat (not always feasible).

(6) ***Compressed Air and Vortex Cooling.*** Compressed air and vortex-type cooling methods present individualized assets and liabilities. Plans to utilize these techniques should be reviewed by the Naval Medical Command *prior to their operation/ use.* The subjective sense of well-being afforded by these methods is not always synonymous with the maintenance of object physiologic

Table 3-12. PHEL Time Limits for PHEL Curves I - VI With the Presence of Fuel Combustion Gases and/or Fuel Vapors [WBGT 80.0-115.0 F]

WBGT Index (F)	Six PHEL Curves (Total Exposure Times In Hours: Minutes)					
	I	II	III	IV	V	VI
80.0	*4:50*	4:15	3:30	2:55	2:15	1:30
81.0	*4:25*	3:50	3:10	2:40	2:00	1:20
82.0	*4:00*	3:30	2:55	2:25	1:50	1:15
83.0	*3:40*	3:10	2:40	2:10	1:40	1:10
84.0	*3:20*	2:55	2:25	2:00	1:30	1:00
85.0	*3:00*	2:40	2:10	1:50	1:25	0:55
86.0	*2:45*	2:25	2:00	1:40	1:15	0:50
87.0	*2:30*	2:10	1:50	1:30	1:10	0:45
88.0	*2:20*	2:00	1:40	1:25	1:05	0:40
89.0	*2:05*	1:50	1:30	1:15	1:00	0:40
90.0	*1:55*	1:40	1:25	1:10	0:55	0:35
91.0	*1:45*	1:30	1:15	1:05	0:50	0:30
92.0	*1:35*	1:25	1:10	1:00	0:45	0:30
93.0	1:30	1:20	1:05	0:55	0:40	0:25
94.0	1:20	1:10	1:00	0:50	0:35	0:25
95.0	*1:15*	1:05	0:55	0:45	0:35	0:20
96.0	1:10	1:00	0:50	0:40	0:30	0:20
97.0	1:05	0:55	0:45	0:40	0:30	0:20
98.0	1:00	0:50	0:40	0:35	0:25	0:15
99.0	0:55	0:45	0:40	0:30	0:25	0:15
100.0	0:50	0:45	0:35	0:30	0:20	0:15
101.0	0:45	0:40	0:35	0:25	0:20	0:15
102.0	0:40	0:35	0:30	0:25	0:20	0:10
103.0	0:40	0:35	0:30	0:25	0:15	0:10
104.0	0:35	0:30	0:25	0:20	0:15	0:10
105.0	0:35	0:30	0:25	0:20	0:15	0:10
106.0	0:30	0:25	0:20	0:20	0:15	0:10
107.0	0:30	0:25	0:20	0:15	0:10	0:10
108.0	0:25	0:25	0:20	0:15	0:10	0:05
109.0	0:25	0:20	0:15	0:15	0:10	0:05
110.0	0:25	0:20	0:15	0:15	0:10	0:05
111.0	0:20	0:20	0:15	0:10	0:10	0:05
112.0	0:20	0:15	0:15	0:10	0:10	0:05
113.0	0:20	0:15	0:15	0:10	0:05	0:05
114.0	0:15	0:15	0:10	0:10	0:05	0:05
115.0	0:15	0:15	0:10	0:10	0:05	0:05

well-being. Furthermore, there is a need to ensure that the quality of the air used in these methods meets breathing quality air standards. In describing the intended use it is essential that the potential ability to provide a continuous air supply, while man is tethered to the filtered air supply outlet, is a reality. Commonly available vortex tubes have no means of ensuring the maximum cooling fraction setting, therefore, it is necessary to describe the positive means of controlling the cooling fraction and locking the control knob in the optimum cooling fraction position (which is rarely at the fully open setting on the vortex tube control valve). Fractional distribution of “cooling” air over the body surface needs to be proportional to that surface area of the body and active muscle sites involved in performing the intended physical work.

(7) ***Other Body Cooling Devices/Attempts.*** Comprehensive physiological and environmental information available to date has not supported the use of liquid cooling, solid carbon dioxide vests, or other such garments worn under regular work clothing in terms of economics, unrestricted body movement, and optimum safety of personnel in shipboard non-emergency situations. There may be highly specialized applications of such units, but each remains to be carefully examined with sufficient supporting data. The key issue is to perform the necessary corrective engineering actions to eliminate impedances of the workers and permit the workers to perform their normal duties in an effective manner without physical encumbrances. In emergency situations, limited use of such body cooling devices may be required, however, the personnel wearing the devices must be fit individuals who are under very close supervision during the emergency events. Historically, attempts at pre-cooling deep body temperatures prior to excessive high heat stress exposures were relatively ineffective in markedly extending personnel exposure times.

3-14. Practical Cold Stress Standards

(1) ***Equivalent Temperature (Wind Chill Index).*** The human body is continually producing heat internally and losing it externally to the environment. A portion of this heat exchange is accounted for by the circulation of air at the skin surface. Increased air velocity thus proportionately increases the loss of body heat. If the ambient air temperature is below freezing and the wind velocity is such that it removes heat from the body surface more rapidly than it can be replaced, frostbite may occur. The combined effect of wind and temperature are given in the Equivalent Temperature Chart, commonly referred to as the Wind Chill Index (Table 3-13). This chart is an expression of the effective temperature acting on exposed body surfaces. In using the chart the estimated (or actual) wind velocity is compared to the dry-bulb air temperature. The equivalent temperature is found where the two columns intersect. For example, at a temperature of – 10 F under calm conditions, the equivalent temperature on exposed body surfaces is the same as that of ambient air, i.e., – 10 F. On the other hand, if the wind velocity increases to 10 miles per hour, the loss of body heat at the skin surface is equivalent to that experienced with no wind at – 33 F. For figures intermediate to those listed in Table 3-13, proportionate interpolations may be made as needed. Table 3-13 also indicates the variabIe dangers of the different equivalent temperatures.

(2) ***Additional Considerations Regarding Equivalent Temperature.*** It should be noted that Equivalent Tem-

Table 3-13. Cooling Power of Wind on Exposed Flesh Expressed as a Equivalent Temperature

Estimated Wind Speed (mph)	Actual Thermometer Reading (F)											
	50	40	30	20	10	0	– 10	– 20	– 30	– 40	– 50	– 60
	EQUIVALENT TEMPERATURE (F)											
Calm	50	40	30	20	10	0	– 10	– 20	– 30	– 40	– 50	– 60
5	48	37	27	16	6	– 5	– 15	– 26	– 36	– 47	– 57	– 68
10	40	28	16	4	– 9	– 24	– 33	– 46	– 58	– 70	– 83	– 95
15	36	22	9	– 5	– 18	– 32	– 45	– 58	– 72	– 85	– 99	– 112
20	32	18	4	– 10	– 25	– 39	– 53	– 67	– 82	– 96	– 110	– 124
25	30	16	0	– 15	– 29	– 44	– 59	– 74	– 88	– 104	– 118	– 133
30	28	13	– 2	– 18	– 33	– 48	– 63	– 79	– 94	– 109	– 125	– 140
35	27	11	– 4	– 21	– 35	– 51	– 67	– 82	– 98	– 113	– 129	– 145
40	26	10	– 6	– 27	– 37	– 53	– 69	– 85	– 100	– 116	– 132	– 148
(wind speeds >40 mph have very little additional effect.)	LITTLE DANGER (for properly clothed person) Maximum danger of false sense of security.				INCREASING DANGER Danger from freezing of exposed flesh.			GREAT DANGER				

Trenchfoot and immersion foot may occur at any point on this chart.

perature (Wind Chill Index) applies only to ***dry skin*** and does not take account of the effect of evaporative cooling. The insulation provided by clothing and the accentuation of heat loss by wet garments are similarly not considered. When estimating the Equivalent Temperature (Wind Chill Index) other causes of increased air circulation over the body should be noted. For instance, the estimated air speed occasioned by walking, running, or riding in an open vehicle must be added to the actual (or estimated) wind velocity when estimating the equivalent surface temperatures. Finally, it is worth remembering that regardless of the wind velocity, the danger of frostbite to ***dry*** exposed body surfaces is negligible as long as the dry-bulb air temperature is above freezing.

(3) ***Special Applications of Equivalent Temperature.*** Although the Equivalent Temperature (Wind Chill Index) can be taken as a practical cold stress standard, special situations may require referral to the Naval Medical Command, Department of the Navy, Washington, D. C., 20372–5 100, for consultation.

(4) ***Median Lethal Exposure Limits:***

(a) Frigid water triggers complex physiological responses that shut down the blood circulation to most parts of the body except heart, lungs and brain. Though the blood contains only a limited amount of oxygen, it can be enough to sustain life and prevent damage to brain tissue for considerable periods of time, once the body's internal temperature has dropped. A cooled-down brain needs less oxygen than one at normal temperature. It takes 10-15 minutes before the deep body temperatures start to drop, surface tissues cool quickly. A victim may experience labored breathing and stiffness of limbs. As core temperature drops to 95 F there will be violent shivering; at 90–95 F, mental facilities cloud; at 86-90 F there is muscular rigidity and loss of consciousness. Below 86 F there is diminished respiration and possible heart failure. Below 80 F, respiration becomes almost undetectable and death is imminent.

(b) There are five cold water immersion ***"DO's":***

1. ***Wear a personal flotation device*** (PFD) or several layers of clothing.

2. ***Try to keep lungs inflated with air*** to maintain bouyancy.

3. ***Use minimum movement*** to prevent the escape of trapped air in clothing, which acts as an insulator.

4. ***Maintain HELP*** (Heat Escape Lessening Posture) ***until help arrives.*** The HELP position is basically a fetal position with arms and legs withdrawn close to the body. ***An alternative is to huddle*** with two or more persons in the water.

5. ***Take advantage of floating objects.***

(c) There are five cold water immersion ***"DO NOT'S":***

1. ***Do not panic!*** Actions within the first 10 seconds can mean survival or death.

2. ***Do not strugg[e.*** Struggling will squeeze insulative air out of clothing and ingesting cold water may constrict breathing passages and induce "dry drowning. "

3. ***Do not swim for [and that's over a mile away.***

4. ***Do not remove clothing.***

5. ***Do not use so-called "drownproofing" techniques in water that is colder than 72 F.*** Drownproofing involves floating almost motionless for long periods, relying on the natural bouyancy of the body and its tendency to hand in a semi-vertical position in water, with the head just breaking the water surface. In cold water, the greatest heat loss is from the head and neck. Since drownproofing requires immersion of those areas, the onset of hypothermia, followed by death, can be brought about with distressing swiftness.

Figure 3-11 illustrates the Hypothermia Median Lethal Exposure (Survival Time Versus Water Temperature) for HELP position, huddling, normal floating with a personal flotation device, treading water and swimming. Hypothermia median lethal exposure times assume that the victim has survived the initial thermal and physical shock of entry into the water.